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THE PHOTOGRAPHIC RECIPROCITY FAILURE IN THE UNDEREXPOSURE REGION

By Clarence E. Weinland

In a recent paper,[1] the author has shown that under certain conditions the failure of the photographic plate to properly integrate an intermittent exposure takes place principally during the early stages of formation of the latent image. Further work along this line has brought out the fact that under similar conditions the reciprocity failure likewise occurs to a far greater extent while the amount of latent image is very small, than when the amount corresponds to a density well up on the time-scale characteristic curve.

The apparatus described in the above paper was used without modification. All experiments described below were upon Cramer Contrast Process plates, which were found to have large intermittency and reciprocity failures under the present conditions. The exposures were made with monochromatic light of λ4358A. The intensity of the light, while not known in absolute units, was well below the optimum for this plate and wave length, as was shown by the steep slope of the Density-Log Intensity curve for constant Exposure. Development conditions were substantially the same as before.

That the intermittency failure occurred during the early formation of the latent image was shown by the formation of an intermittency "loop" when exposures partly continuous and partly intermittent, though all of the same energy, were given. In the present instance, a reciprocity "loop" is found to result when light of low intensity is substituted for the intermittent parts of the exposures.

Fig. 1 shows both an intermittency and a reciprocity loop. Four series of exposures were made upon each pair of two plates, the first with the continuous part of each exposure preceding the intermittent, the second with the intermittent preceding the continuous, the third

[1] Clarence E. Weinland, J.O.S.A. & R.S.I., *15*, p. 337; 1927.

with high intensity preceding low, and the fourth with the low intensity part of each exposure given first. The intensity of the source was kept constant in all cases, the intermittent exposures being produced by rotating a sector of transmission 6.25% in the beam, giving approximately 80 flashes per second, while the low intensity exposures were produced by the insertion of a screen of transmission 6.76% into the beam. In the intermittent and low intensity exposures the time had to be extended in order to keep the total energy of the exposure constant, so equivalent seconds of intermittent exposure were multiplied by 16 in order to get the actual time necessary, while those

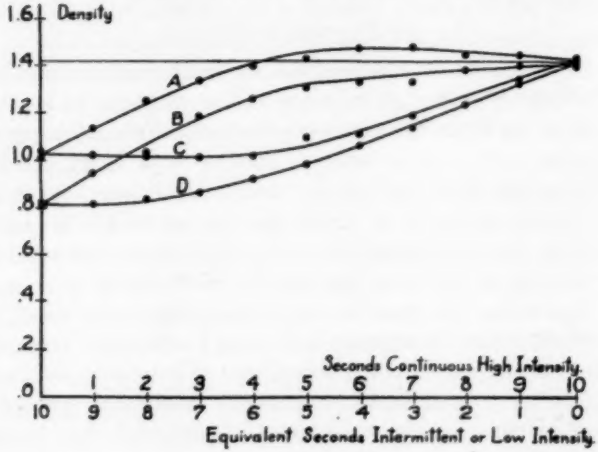

FIG. 1.

Intermittency Loop { *A—Continuous preceding intermittent* / *C—Intermittent preceding continuous.*

Reciprocity Loop { *B—High intensity preceding low intensity* / *D—Low intensity preceding high intensity.*

of low intensity were multiplied by 14.8. All exposures for the intermittency loop were at the same intensity as the high intensity exposures for the reciprocity loop, and all exposures for the reciprocity loop were continuous.

The formation of the loop in each case indicates clearly that when a continuous exposure is followed by an intermittent or low intensity one, the density produced is greater than when the conditions are reversed and the same energy is given with the intermittent or low intensity part first. This means that when an intermittent or low intensity exposure is given first, it does not produce the same amount of latent image as when the latent image has already been built up to a

considerable degree by high intensity continuous exposure, or in other words, that the intermittency and reciprocity failures, for this particular set of conditions, takes place mainly during the beginning of latent image formation.

An examination of the loops brings out the suggestion that after a certain point, a previous exposure to continuous radiation may cause an intermittent exposure to give more density than a continuous one, as shown by the rounded top of the intermittency loop rising to a greater density than that from an entirely continuous exposure. Also in no case did the low intensity exposure integrate properly, as shown by the sloping top of the reciprocity loop. Both these effects have been observed a number of times under these conditions, and on different brands of plate at various wave lengths. The toe of the intermittency loop being at a higher density than that of the other loop is in accord with the conclusion of the previous paper, to the effect that the reciprocity failure under these conditions is greater that the intermittency failure.

In the previous paper it was stated that the upper limb of the intermittency loop intersected the horizontal at the point where the continuous pre-exposures had reached the straight line portion of the time-scale characteristic curve, or in other words that intermittent exposure on the straight line portion of the curve was integrated in the same manner as continuous. This seems not to always be the case, however, as subsequent work has shown that under certain conditions the characteristic curve does not become truly straight until densities considerably higher than those used are reached, if at all.

The occurrence of these loops gives another bit of evidence supporting the suggestion put forth in the previous paper, to the effect that the reciprocity and intermittency failures bear an intimate relation with one another, and may prove to be of common origin. In this connection it may be stated that L. A. Jones has mentioned in correspondence that he has obtained definite results verifying the suggestion of Davis,[2] to the effect that intermittent exposure above the optimum intensity tends to give an increased density, while below the optimum the density is decreased as compared with continuous exposure. It is also interesting that the dependence of the reciprocity failure upon the optimum intensity has been clearly shown by Jones and Huse.[3]

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[2] Raymond Davis, Scientific Papers of the Bureau of Standards, No. 528.
[3] Loyd A. Jones and Emery Huse, J.O.S.A. & R.S.I., *12*, p. 1079; 1923.

A QUICK METHOD OF REDUCING PRISMATIC SPECTRA

By H. N. Russell and A. G. Shenstone

Hartmann's method for the reduction of plates obtained with prism spectroscopes is of wide applicability and its author is undoubtedly right in his claim that the formula

$$\lambda - \lambda_0 = C/(x - x_0)$$

(x being the scale-reading for the spectral line) contains as few constants as is possible in any general formula for such reductions.

In practice, however, reductions by this formula are laborious, for the division of C by $x - x_0$, which must be carried out to six significant figures, must be made separately for each line, and, even with a calculating machine, costs much time. Moreover, what the modern student of spectra most desires are the frequencies which have to be derived from the resulting wave lengths. A method in use in various laboratories, including the Jefferson Laboratory at Harvard, depends on the fact that $\Delta\nu/\Delta x$ is very nearly a linear function of x. This suggests the quadratic formula

$$\nu = \nu_0 + ax + bx^2$$

The first test showed that this held true, with remarkable accuracy, in the case of a large quartz spectrograph, and it has since been found to be equally useful for other quartz and glass spectrographs. Though containing the same number of constants as Hartmann's, the quadratic formula is much more rapid in practice. It is best written in the form

$$\nu = \nu_0 + ax + A - b(x - x_m)^2$$

in which the quantities are as follows: ν_0 is the frequency of the standard of longest wave length; a is the difference between the greatest and least standard frequencies divided by their distance on the plate; A is the maximum of the curve of $(\nu - \nu_0 - ax)$ plotted against x; x_m is some point near the center of the range; b is A divided by x_m^2. The constants a, A, and b may then be determined from three standard lines. The term $b(x - x_m)^2$ is almost always small enough to be read with sufficient accuracy from a 20-inch slide rule. The slide is set to the fixed constant b, and the values read off as rapidly as the run-

ner can be set to the values of $x-x_m$. The quantities ν_0+ax may be readily ground out in an arithmometer. Setting the constant a on the upper part of the machine, and ν_0 on the carriage below, the usual operation of multiplication by x leaves the value ν_0+ax on the carriage. Treating this as in the "long division" operation, with x as quotient, restores the carriage to the reading ν_0, more quickly than it can be cleared and reset to this value.

This process is much more rapid than the division of the constant C in Hartmann's method, by $x-x_0$, which must be set up separately each time.

Like all empirical formulas, this one is not rigorous, and its results must be corrected by means of a curve of the residuals for known lines. These residuals, however, are, in our experience, so small as to afford no trouble.

This statement, however, does not apply to all types of instrument. For the large stellar spectrograph at Mt. Wilson, which has glass prisms and achromatic lenses, the quadratic formula is not even a tolerable first approximation, and is practically useless.

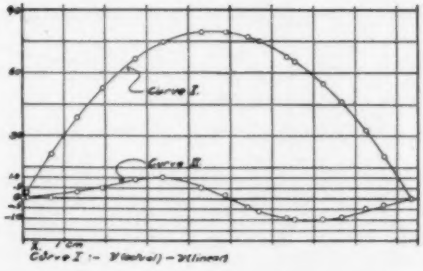

FIG. 1. *Curve I:—ν (actual)—ν (linear). Curve II:—Residuals. Scale 10 times curve I. λ4780 to λ4213. Fe.*

The applicability of the formula here suggested is therefore limited to instruments of certain types, but for these it is much more rapid than any other. Very little labor is required to test it upon the measures of eight or ten known lines well distributed along the length of a plate, so that a trial of its application is well worth while.

Three illustrations of the curves obtained by the formula are given as follows.

Fig. 1. The plate was taken on a Hilger *E*.1 glass spectrograph and the wave length range is λ4789 to λ4213 of the iron arc. Curve I is

the curve of the differences ν(actual) $-\nu$(linear). Its maximum gives the constant A. Curve II is the final correction curve of residuals plotted on a ten times larger scale. It has a maximum of 1.0 wave-numbers.

FIG. 2. *Residuals. λ5446 to λ5083. Fe.*

Fig. 2. The plate was from the same spectrograph as Fig. 1 but set in its longer wavelength range. The maximum of the curve of residuals is at only .3 wave numbers.

Fig. 3. The plate was taken on a similar quartz spectrograph focused for its range of shortest wavelengths. The lines used are the Cu II lines calculated by one of us by an application of the combination

FIG. 3. *Residuals. λ2085 to λ1944. CuII.*

principle to that spectrum. The maximum of the curve is at 1.8 wave-numbers, and the points do not fall off the curve by as much as the estimated accuracy of the lines, $\pm .2$ wave-numbers.

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PHYSICAL OPTICS*

SUPPLEMENTARY REPORT OF PROGRESS COMMITTEE FOR 1926–7.

THE NEW QUANTUM MECHANICS

The developments of the past year in the new quantum mehanics are not quite so spectacular as those of the preceding year sketched in last year's report[1] of this committee, but nevertheless there has been great progress both in refinement of theory and in comprehensiveness of application.

From the standpoint of abstract theory probably the greatest advance of the year is the new interpretation of the quantum mechanics developed by Dirac[2] and also in more or less equivalent form by Jordan[3]. This new formulation is partly an extension of previous work by Heisenberg[4], London,[5] and Pauli,[6] and is of great philosophical as well as physical interest, for it indicates a quite different type of kinematical determinateness in atomic phenomena than in ordinary large scale events. An exact description of the Dirac-Jordan ideas would unfortunately take us too far afield into the mathematical theory of matrix or tensor transformations. We may merely mention that a basic feature is that it is illegitimate to speak of a simultaneous pair of values q, p for a coordinate q and its conjugate momentum p. Instead, if q be specified within a limit of error q_1, then, as so nicely stressed in a recent paper by Heisenberg,[7] p can only be specified within a limit of error p_1, where the product p_1q_1 is of the order of magnitude of Planck's constant ($p_1q_1 \sim h$). Thus high accuracy in the determination of q implies low accuracy in the determination of p, and vice versa, and it is only when dealing with amounts of action large compared to Planck's constant that we have our ordinary geometry of events. More generally, if f and g be two dynamical variables which do not commute with each other in multiplication one can no longer correlate definite numerical values of f and g with each other and one can only speak of the probability that g will have a certain value if f is given, or vice versa. Thus within the atom we can calculate only what *may* happen rather than what *will* happen, but the ambiguity in the future is not so much due

* This material was prepared by Dr. J. H. Van Vleck. It was intended to be included in the original report of the Committee on Physical Optics which was published in this Journal, *16*, p. 44; 1928. This portion of the report however was lost in transit. It has now been revised by Professor Van Vleck and is submitted by the committee on Physical Optics as a supplementary report (Editors).

to breakdown in the ordinary laws of cause and effect as to the inevitably indeterminate character of the initial conditions. Dirac shows that this indeterminateness is responsible for the time-honored puzzle of where the ejected photo-electron receives its energy, for he notes the coupling energy of the light-wave and atom is not[8] a magnitude which can be assigned a numerical value simultaneously with the stationary state of the atom and the energy of the incident radiation.

The new Dirac-Jordan theory includes the Born-Heisenberg matrix theory as a special case, and so gives the same results for spectral intensities, frequencies, etc., but goes a step further inasmuch as it furnishes a foothold for attacking such problems as the collisions of electrons with atoms, the interaction of atoms and radiation, etc. Born's[9] treatment of collisions as a sort of diffraction problem seemed at first to follow a rather different channel than other forms of quantum mechanics, but is now found to be comprised in the general Dirac-Jordan theory. The monumental work of Dirac[10] furnishes at last a dynamics for handling the "back-action" due to an electron's own radiation, and in a certain sense a mechanism is thus found for the previously rather mysterious spontaneous quantum jumps, while the forced transitions induced by radiation have been treated by Dirac[11], Born[12], and Slater[13]. The new view of atomic dynamics removes much of the discrepancy between light-quanta and the wave theory of light, for Heisenberg[4] has shown that the correct statistical averages can be obtained with light quanta even though the coupling between atoms is continuous. The Schrödinger wave equation, of course, retains its preeminent place, but a new interpretation is given to the Schrödinger wave function. This function is regarded as determining a transformation matrix, and its square plays the role of a sort of probability function. This statistical view is to be contrasted with the many efforts[14] which have been made to make a determinate hydrodynamical model of the atom with the wave function determining the charge density. Instead the Dirac-Jordan interpretation of the atom is a semi-statistical one, and intimately related to the Einstein-Bose-Fermi statistics. There is an illuminating asymptotic connection[15] between the quantum expressions for averages and probablities with the classical ones in the limit $h=0$, and this tends to increase our faith in the statistical viewpoint. The concept of an electron as a wave of matter is, of course, still an exceedingly useful one in visualizing many experiments if not taken too literally; the term "wave of probability" would probably be more legitimate.

Let us now turn to some concrete applications of the quantum mechanics to specific problems, which in most spectroscopic cases can be handled by the ordinary matrix or wave theories without the Dirac-Jordan extensions. Many papers[16] of the year may be roughly characterized as simply deriving by the wave method results mostly aready obtained with the chronologically earlier matrix theory. The "clearing up" of the hydrogen spectrum by the new quantum mechanics and spin electron was reported a year ago, and so the advances of the past year in calculating spectroscopic terms have been primarily in non-hydrogenic atoms, although there have been some interesting computations[17] on intensities of the continuous band beyond the series head in hydrogen. Heisenberg[18] has made with a fair degree of accuracy the difficult and involved calculation of the term values of excited states of neutral helium, and some closer approximations have been considered by Sugiura.[19] Approximate computations of the ionization potential of the normal helium atom have been made by Slater[20], Kellner[21], and Sugiura.[19] The energy of the normal hydrogen molecule-ion has been calculated by Burrau[22], and the normal hydrogen molecule by Condon[23], Sugiura[24], and Wang.[25] The agreement with experiment is remarkably satisfactory in view of the approximate nature of the calculations. In heavier atoms accurate calculations of term values are increasingly difficult, but good approximations have been obtained in some instances by Unsold[26] and by Sugiura,[27,28] and Urey.[27] A theoretical basis for the Rydberg formula $R/(n+\delta)^2$ has been given by Slater.[29] The results are often roughly the same as with half-quanta in the old quantum theory, and the general theoretical basis for this agreement has been explained by Kramers.[30] In the field of molecular rather than atomic spectra Hund[31] has written three important papers which elucidate many previously rather mysterious points, especially the adiabatic formation of molecules out of atoms. This subject has been further treated by Heitler and London,[32] and London[33] has amplified it into a quantum theory of homopolar valences. Condon[34] has given a theoretical basis for Franck's[35] semi-empirical theory of the large vibrational transitions associated with electron bands. The peculiar alternating intensities in the band spectra of non-polar molecules, also many other features of the classification of non-hydrogenic spectra and even the specific heat of hydrogen,[36] seem explicable on the basis of the Pauli exclusion principle and the remarkable Heisenberg resonance effect associated with interchanges of like particles.[37]

Turning now to a rather different field from spectroscopic terms, we have already mentioned Born's much-needed theory[9,38] of the collisions of electrons with atoms or molecules, and of the excitation of spectra by impact. Born[39] has been able to carry through his general theory to specific numerical conclusions in the case of collisions with hydrogen atoms, where he has calculated numerically the scattering and excitation coefficients. The theory is confirmed at least qualitatively in the diffraction-like maxima and minima found in Dymond's work on the spacial distribution of the electrons scattered by helium gas, and in the already famous Davisson-Germer experiment on the scattering of electrons by single crystals. Both these experiments have been discussed earlier[40] in the report. One of the most interesting spectroscopic phenomena associated with electronic bombardment is the polarization of radiation excited by electron impact, and the theory of this has recently been developed by Oppenheimer.[41] The theory of the scattering of alpha particles has been treated by Wentzel,[42] de Broglie,[43] and Oppenheimer.[44] Here the distribution formulas are very nearly the same as with classical theory,[45] and this agreement shows why the latter could explain Rutherford's classic experiments so well. The stopping of alpha particles has been considered by Gaunt,[46] and their capture by Oppenheimer.[47] Real progress is at last being made on the theoretical explanation of the baffling Ramsauer effect.[48] Several articles[49] have been written on the Compton effect in the new mechanics. We may mention especially recent papers by Wentzel,[50] which give the theory of the Compton effect for bound rather than free electrons, and which show how to investigate theoretically such subjects as the relative intensities of the modified and unmodified lines. The discussion of the many interesting applications of the quantum mechanics to dielectric constants and magnetism is beyond the scope of the present report.[51] We cannot, however, fail to mention that Pauli's explanation[52] by means of the Fermi statistics of how the low magnetism of alkali metals is compatible with the spin electron has opened new vistas in the electron theory of metallic conduction. The conduction electrons are so close to each other that there is even under standard conditions an effect similar to the "degeneration" required by the Einstein-Bose-Fermi statistics for gases at extremely low temperatures and high pressures. Pauli's ideas have been greatly amplified by Sommerfeld,[53] and at last we have at least a clue to the solution of many mysteries of electron conduction, such as how the low contribution of electrons to specific

heats is to be reconciled with the large number of conduction electrons required by the optical properties of metals.

REFERENCES

[1] J.O.S.A. & R.S.I., *14*, p. 108; 1927. The present section on quantum mechanics is essentially an extension of that in last year's report, and so can advantageously be read in conjunction with this.

[2] Dirac, Proc. Roy. Soc., *113A*, p. 621; 1927.

[3] Jordan, ZS. f. Phys., *40*, p. 809; 1926; and *41*, p, 797; 1927. Non-mathematical surveys of the statistical aspects of the new interpretation of the quantum mechanics have been given by Born, Nature, *119*, p. 354; 1927; and Jordan, Ibid., *119*, p. 566; 1927. An excellent critique is given by Heisenberg (ref. 7 below) and a good survey of the whole quantum theory has been written by Jordan in die Naturwissenschaften, *15*; p. 614 and p. 636; 1927. Modifications in the Dirac-Jordan theory which are necessary when applying it to dynamical variables which assume discrete rather than continuous values are given by Jordan in ZS. f. Phys., *44*, p. 1; 1927. Mathematical amplifications of the theory have been developed by Hilbert, Neumann, and Nordheim, Math. Ann., *98*, p. 1; 1927; Neumann, Göttingen Nachrichten, May 20, 1927; Weyl, ZS. f. Phys., *46*, p. 1; 1927. Applications to special simple types of motion have been considered by Kennard, ZS. f. Phys., *44*, p. 326, 1927.

[4] Heisenberg, ZS. f. Phys., *40*, p. 501; 1926. See also Jordan, *Ibid.*, *40*, p. 661; 1926.

[5] London, ZS. f. Phys., *40*, p. 193; 1926.

[6] Pauli, mostly unpublished. See, however, ZS. f. Phys., *41*, p. 81; 1927.

[7] Heisenberg, ZS. f. Phys, *43*, p. 172; 1927.

[8] Dirac, Proc. Roy. Soc., *114A*, p. 243; 1927.

[9] Born, ZS. f. Phys., *38*, p. 803; 1926.

[10] Dirac, Proc. Roy. Soc., *114A* p. 243, and p. 710; 1927; ZS. f. Phys., *44*, p. 585; 1927.

[11] Dirac, Proc. Roy. Soc., *112A*, p. 661; 1926; also preceding reference.

[12] Born, ZS. f. Phys., *40*, p. 167; 1926.

[13] Slater, Proc. Nat. Acad. Sci., *13*, p. 7 and p. 104; 1927.

[14] Schroedinger, Ann. der Phys., *81*, p. 109; 1926; *82*, p. 265; 1927.
Gordon, ZS. f. Phys., *40*, p. 117; 1926.
Madelung, ZS. f. Phys., *40*, p. 322; 1926.
Klein, ZS. f. Phys., *41*, p. 407; 1926.
Debye, Phys. Zeits., *28*, p. 170; 1927.
Bateman, Phys. Rev., *30*, p. 55; 1927.
Darwin, Proc. Roy. Soc., *116A*, p. 227; *117A*, p. 258; 1927.

[15] VanVleck, Proc. Nat. Acad. Sci., Feb. 1928 and references.

[16] Brillouin, Journal de Physique, *8*, p. 74; 1927.
Darwin, Proc. Roy. Soc., *115A*, p. 1; 1927.
Epstein, Proc. Nat. Acad. Sci., *13*, p. 232 and p. 432; 1927.
Fues, Ann. der Phys., *81*, p. 281; 1926.
Kronig and Rabi, Phys. Rev., *29*, p. 262; 1927.
Manneback, Phys. Zeits., *28*, p. 72; 1927.
Pauli, ZS. f. Phys., *43*, p. 601; 1927.
Reiche, ZS. f. Phys., *39*, p. 444; 1926; Rademacher and Reiche, *Ibid.*, *41*, p. 453; 1927.
Richter, Proc. Nat. Acad. Sci., *13*, p. 476; 1927.

[17] Oppenheimer, ZS. f. Phys., *41*, p. 268; 1927.
Sugiura, Journal de Physique, *8*, p. 113; 1927.

[18] Heisenberg, ZS. f. Phys., 39, p. 499; 1926.

[19] Sugiura, ZS. f. Phys., *44*, p. 190; 1927.

[20] Slater, Proc. Nat. Acad. Sci., *13*, p. 423; 1927.

[21] Kellner, ZS. f. Phys., *44*, p. 91; 1927.
[22] Burrau, Det. Kgl. Danske Vid. Selskad; Math.-fys. Medd., *7*, No. 14; 1927.
[23] Condon, Proc. Nat. Acad. Sci., *13*, p. 466; 1927.
[24] Sugiura, ZS. f. Phys., *45*, p. 484; 1927.
[25] Wang. Phys. Rev., April 1928.
[26] Unsöld, Ann. der Phys., *82*, p. 355; 1927.
[27] Sugiura and Urey, Det. Kgl. Danske Vid. Selskad; Math.-fys. Medd., *7*, No. 13; 1927.
[28] Sugiura, Phil. Mag., *4*, 495; 1927.
[29] Slater, Phys. Rev., *31*, p. 333; 1928.
[30] Kramers, ZS. f. Phys., *39*, p. 828; 1926.
[31] Hund, ZS. f. Phys., *40*, p. 742; 1926; *42*, p. 93; 1927; *43*, p. 805; 1927.
[32] Heitler and London, ZS. f. Phys., *44*, p. 455; 1927.
[33] London, ZS. f. Phys., *46*, p. 455; 1928.
[34] Condon, Proc. Nat. Acad. Sci., *13*, p. 462; 1927.
[35] Franck, Trans. Faraday Soc., 1925.
[36] Dennison, Proc. Roy. Soc., *115A*, p. 483; 1927.
[37] Heisenberg, ZS. f. Phys., *41*, p. 239; 1927; also Hund, ref. *31* and ZS. f. Phys., *43*, p. 788; 1927; Wigner, ZS. f. Phys., *40*, p. 492, 883; *43*, p. 624 and *45*, p. 601; 1927.
[38] As a simple illustration of Born's theory, collisions with a rotating dipole have been discussed by Fermi, ZS. f. Phys., *40*, p. 399; 1926.
[39] Born, Göttingen Nachrichten, p. 146; 1926.
[40] J.O.S.A. & R.S.I., *16*, p. 57; 1928.
[41] Oppenheimer, ZS. f. Phys., *43*, p. 27; 1927; Proc. Nat. Acad. Sci., *13*, p. 800; 1927.
[42] Wentzel, ZS. f. Phys., *40*, p, 590; 1926.
[43] De Broglie, Ondes et Mouvements, Paris 1927.
[44] Oppenheimer, ZS. f. Phys., *43*, p. 413; 1927.
[45] Cf. Blackett, Proc. Cambr. Phil. Soc., *23*, p. 698; 1927; also Oppenheimer, Phys. Rev., *31*, p. 66; 1928.
[46] Gaunt, Proc. Cambr. Phil. Soc., *23*, p. 732; 1927.
[47] Oppenheimer, Phys. Rev., *31*, p. 349; 1928.
[48] Mensing, ZS. f. Phys., *45*, p. 603; 1927; Oppenheimer, Proc. Nat. Acad. Sci., *14*, p. 261; 1928.
[49] Dirac, Proc. Roy. Soc., *111A*, p. 405; 1926; and Proc. Cambr. Phil. Soc., *23*, p. 500; 1927. Gordon, ref. 14.
Schroedinger, Ann. der Phys., *82*, p. 257; 1927.
[50] Wentzel, ZS. f. Phys., *43*, p. 1; and *43*, p. 779; 1927.
[51] See references 56 of last year's report,[1] also Brillouin, loc. cit.[14], Kronig, Proc. Nat. Acad. Sci., *12*, p. 608; 1926; ZS. f. Phys., *45*, p. 458 and p. 508; 1927 (Kerr and Faraday effects); Manneback, ref. 16; Pauling, Proc. Roy. Soc., *114A*, p. 181; Sommerfield and Laporte, ZS. f. Phys., *40*, p. 333; 1926; VanVleck, Proc. Nat. Acad. Sci., *12*, p. 662; 1926; Phys. Rev., *29*, p. 727; *30*, p. 31; 1927; also April 1928.
[52] Pauli, ZS. f. Phys., *41*, p. 81; 1927.
[53] Sommerfeld, Naturwissenschaften, *15*, p. 825, 1927; ZS. f. Phys. vol. 47.

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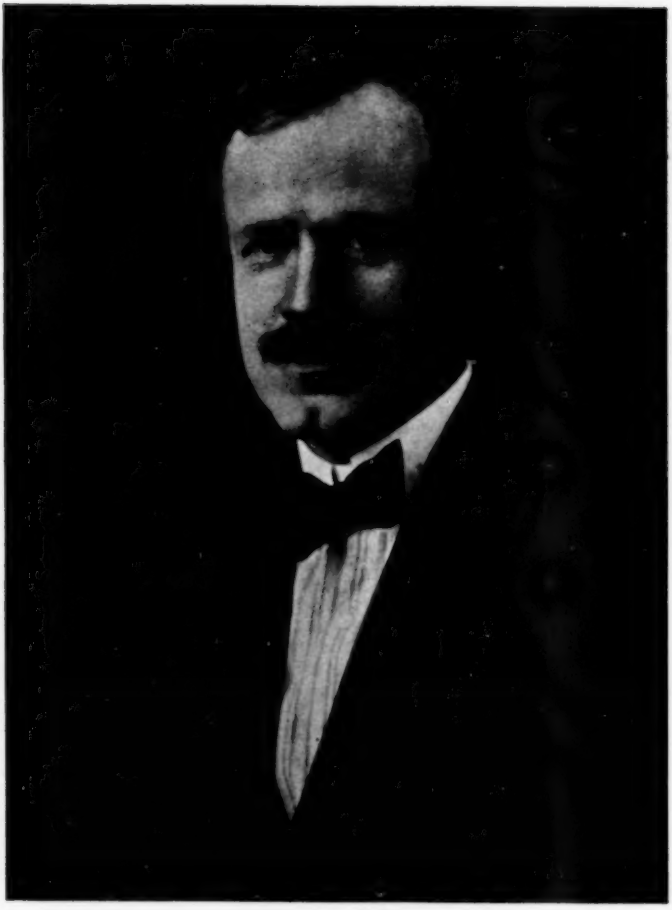

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TEMPERATURE RADIATION*

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The study of the radiation from different substances has been in progress for a good many years. More progress, however, has been made in the past forty or fifty years than in all the years before this time. It was about fifty years ago that the idea of temperature as applied to what we now call high temperature began to take on a real meaning. The idea of the standard radiator, the black body, was brought out at about this time and studies were undertaken to see how some of the more common substances radiated.

The ideal black body as defined is rather a simple thing. Using a very short definition the black body is one that will absorb all radiation that falls upon it. To make this possible certain conditions can be laid down. No radiation is to be reflected or transmitted. Thus, it must have a reflection factor of zero and a very large absorption coefficient, or must have a finite thickness. Starting with this definition many of the properties of this ideal radiator can be developed. It can be shown that the black body radiates more energy for any or all wave-length intervals than any other body that owes its radiation to temperature alone. These various properties of the ideal radiator have been designated the black body laws.

The laws that really make this radiator so valuable are the ones that tie up in a definite way the intensity of the radiation and the temperature. The Stefan-Boltzman law, which was first worked out empirically and later theoretically, gives the relation between the temperature and the total energy radiated, and is recognized as one of the fundamental laws of the black body. This law states that the total radiation varies as the fourth power of the temperature.

The next thing of interest is how the energy is distributed with respect to wave lengths for any temperature. Wien attacked this problem and derived his displacement law, which gave considerable information about the distribution of energy.

1. It gave the general form of the law for the distribution and showed that it was a function of a single variable, i.e the product of the temperature and wave-length. 2. It showed that this product, i.e. $\lambda \cdot T$, for the position of the maximum of energy was a constant, and thus that

* Retiring President's address delivered before the Optical Society of America at the Twelfth Annual Meeting, Schenectady, N. Y., October 20–22, 1927.

this maximum of energy shifted towards short wave-lengths as the temperature was increased. 3. It showed that the intensity of the energy for this maximum varied as the fifth power of the temperature.

The theory had advanced about this far before anyone had shown how to practically realize the black body, but shortly thereafter considerable work was done on the construction of black bodies and the measurement of their radiation.

Wien followed up his displacement law with his radiation law, which is so well known. However, it was soon shown that this law would not fit the facts for the entire range of temperatures and wave-lengths. It was all right for short wave-lengths and low temperatures, but would not do for long wave-lengths or high temperatures. In other words, the law was shown to be in very good agreement with experimental results for values of the product λT less than 3000. This was one of the serious disagreements between theoretical and experimental physics which have occurred in modern times. Experimental physics triumphed and the theoretical men had to work out a new relation. Planck's law was the result. This law represented the facts known at the time well within experimental error, and has since been tested and is now known to represent the facts as accurately as they can be measured even with the best modern methods.

Without discussing the assumptions underlying this radiation law, it may be pointed out that these assumptions almost completely upset previous ideas as to radiation. Even after twenty-five years of very active work the picture of the quanta introduced in these assumptions is not complete, nor has it been overthrown. Indeed, for the most part, it seems that the idea of quanta in radiation is very near the facts.

As an illustration showing how well black bodies can be constructed and standardized in different laboratories,[1] a temperature intercomparison carried on by the Research Laboratory at Nela Park is a good example. The temperatures of a number of tungsten lamps for different currents were measured by an optical pyrometer that had been calibrated against a standard black body for a particular wave-length and temperature. Then these lamps were sent around to different laboratories with the request that they measure these temperatures in terms of their temperature scales. The lamps were sent to the Physics Department of the University of Wisconsin, the Bureau of Standards, the National Physical Laboratory in England, and the Reichsanstalt. The

[1] Astrophys. J., *58*, p. 294; Dec. 1923.

agreement between 1400° and 2400°K was very good, the maximum difference being about 4 or 5°.

The black body has been proposed several times as a standard of light as well as a standard of radiation. Different suggestions have been made, one of then being that the black body operated at the temperature of melting platinum be chosen as an ultimate standard of light. The brightness, that is the candles per square centimeter in a given direction, of the black body has been measured a number of times. The results obtained by the Research Laboratory at Nela Park are in very good agreement with other experimental results. The brightness of a black body at different temperatures can be calculated from the distribution of energy as given by Planck's equation and the average visibility curve, and this result expressed in lumens, providing the mechanical equivalent of light is known. The mechanical equivalent of light is the relation between the light unit and the energy unit and may be expressed as the least amount of energy in watts necessary to produce one unit of light flux, that is one lumen. From measurements of the candle power of a black body at different temperatures this constant can be calculated.

Ives[3] has made several determinations of the brightness of the black body at different temperatures and also several determinations of the mechanical equivalent of light. Lately he has collected all of the different values and reduced them to the values of the constants of the radiation laws that are now accepted ($C_2 = 14330$; $\sigma = 5.70910^{-12}$) and arrived at a mechanical equivalent of light of .00161 watts/lumen. Using this mechanical equivalent of light and the best visibility data available, Ives has calculated the brightness of a black body for a temperature range of about 1200–10,000°K and compared them with the experimental values obtained in the research Laboratory at Nela Park. These results are shown in Table 1.

In Fig. 1, Curve *A*, are shown the efficiency in lumens per watt of a black body at different temperatures calculated from such brightnesses. From these results it can be seen that the value of the efficiency of a black body increases up to about 6700° where it reaches a maximum from which it again decreases. At this temperature the efficiency of a black body is about 85 lumens per watt.

The question is often asked what would be the efficiency of a black body if it were possible to suppress the infrared and ultraviolet parts

[3] J.O.S.A., *12*, p. 75; Feb. 1926.

of the energy, thus producing a white light without the accompanying ultraviolet and infrared energy. Making use of the energy distribution in the black body as published by the Bureau of Standards, the percentage of the energy of a black body radiated between the wave-

TABLE 1. *Black body luminous characteristics.*

T, Degrees absolute	Radiant luminous efficiency	Brightness, b, in candles per cm.^{2} Computed for $m = .00161$	Brightness, b, in candles per cm.^{2} Observed, Hyde, Forsythe, and Cady
1200	0.00000602	0.0141	
1400	0.0000557	0.242	
1600	0.000282	2.08	
1700	0.000541	5.10	5.0_8
1750	0.000726	7.69	7.6_3
1800	0.000957	11.3	11.2
1850	0.00124	16.4	16.2
1900	0.00158	23.2	23.0
1950	0.00198	32.3	32.0
2000	0.00246	44.4	44.0
2050	0.00301	59.9	59.6
2100	0.00364	79.8	79.6
2150	0.00436	105.	104.9
2200	0.00517	137.	136.4
2250	0.00606	175.	175.
2300	0.00706	223.	222.
2350	0.00816	281.	280.
2400	0.00935	350.	350.
2450	0.0107	433.	433.
2500	0.0120	531.	527.
2550	0.0135	645.	641.
2600	0.0151	780.	775.
2650	0.0168	934.	927.
3000	0.0309	2.83×10^3	
4000	0.0807	2.33×10^4	
5000	0.1190	8.40×10^4	
6000	0.1353	1.98×10^5	
7000	0.1352	3.67×10^5	
8000	0.1258	5.82×10^5	
10000	0.0987	1.115×10^6	

lengths .40μ and .76μ was calculated. The results obtained are shown in Curve *B* of Fig. 1. It is shown that the percentage of energy within the visible spectrum increases from a very low value at low temperatures to a maximum of about 44% for a temperature corresponding to about 6700°K. In Curve *C* of this figure is shown the efficiency one

might expect if it were possible to suppress the infrared and ultraviolet radiation and at the same time maintain the radiation in the visible spectrum. This curve has a maximum corresponding about to that of Curve *A* and gives an efficiency of about 198 lumens per watt. It is thus seen that if one watt of energy were used to produce light with the black body as a source, the maximum one could hope to get would be 85 lumens. If it were possible to suppress the ultraviolet and infrared radiation, we could increase this up to about 198 lumens, which is the upper limit, then, for white light. Of course, this value can be increased several per cent by changing the limits of the visible spectrum. Very little light is produced by energy near the extreme limits, that is near

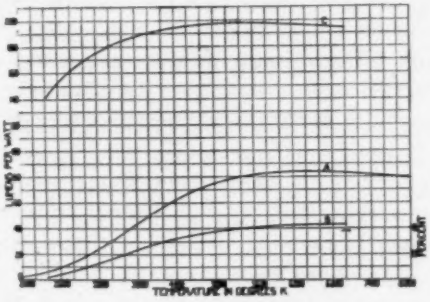

FIG. 1. *Some radiational characteristics of a black body for different temperatures. Curve A. Lumens per watt. Curve B. Percentage of the energy between the wave-length limits 0.4μ and 0.76μ. Curve C. Lumens per watt for the energy between the wave-length limits 0.4μ and 0.76μ.*

.40 and 76μ, while there is considerable energy at the longer wave-lengths. This might be increased up to as much as 250 lumens per watt without very greatly affecting the color of the light.

Now, going the other way just as far as possible, if the energy were all expended to produce light at the wave-lengths for which the eye is the most sensitive, i.e. at about wave-length .55μ, the result would be about 620 lumens per watt. The light would be green, somewhat similar to that produced by a mercury arc. Quite unfortunately, no one knows how to build a black body that can be operated at 6700°K and thus obtain the 85 lumens per watt, nor is it known how to suppress the ultraviolet and infrared part of the spectrum, thus increasing this by a factory of 2 or 3.

There are two difficulties that stand out in any study of temperature radiation. The first is to heat the substance to the desired brightness and to keep it constant, and second is to be able to measure its tem-

perature. Electrical heating overcomes the first difficulty; thus, the first substances studied were the metals, and the first of these were the metals that could be operated in air without surface changes due to oxidization.

The radiation from tungsten and platinum has probably been studied more than that from other metals. Platinum was studied first because it is easy to work and was also used for so many purposes where a knowledge of temperature was desirable.

Practically no information can be gained concerning radiation from metals and other substances by heating them in an enclosed furnace, since the reflection from the walls and other parts of the furnace builds up conditions of radiation that are somewhere between that of the substance investigated and a black body.

In the first work with platinum the temperature was determined by means of small thermocouples attached to a surface or by melting small bits of substances on the surface. The thermocouples did not give altogether satisfactory results, since even very small wires conducted away some heat which lowered the temperature. Some gain in accuracy was obtained by using varying sizes of small thermocouples and extrapolating to zero diameter. It was finally recognized that a very good method would be to build a black body out of the substance investigated which would enable the temperature to be obtained from the black body. Mendenhall[3] first accomplished this by a very interesting device. He used thin strips of metal folded into the form of a narrow wedge. He showed theoretically that for a metal with a reflection factor corresponding to that of platinum a wedge with a 10° opening and a few millimeters wide would give almost perfect black body emission for radiation from the inside. He built such a wedge with platinum and obtained a very good check on the known radiation characteristics of platinum. For this to be satisfactory the wedges must be very carefully made and the material used must not be too thick.

A natural question to raise is the relation between the temperature on the inside of the *V* and on the outside. A simple calculation will show that for metals with high heat conductivity no very great temperature difference will be maintained on the two sides of a piece of metal a few tenths of a millimeter thick if it is electrically heated. This difference will be only a degree or so at very high temperatures for a tube with walls 1mm thick if it is electrically heated.

[3] Astrophys. J., *33*, p. 91; March 1911.

The emissivity of carbon was investigated by the wedge method.[4] It was found that different values were obtained depending upon the the thickness of the carbon used to make the wedges. Several different thicknesses were used and extrapolation made to zero thickness that gave values of emissivity agreeing well with other determinations.

McCauley[5] used this wedge method for determining the temperature of samples of metals in an investigations of the infrared radiation from platinum and palladium. Burgess and Foote[6] at the Bureau of Standards used this method in a study of the radiation from the nickel oxide. They used a nickel wedge and obtained the temperature from the inside of the wedge and the radiation constants of the oxide from observations on the outside. They studied the radiation characteristics of the oxide as a funtion of its thickness.

Spence[7] has used this method in several investigations of infrared radiation.

No one has yet worked out a general equation that will represent the radiation from non-black bodies, so results are given in several diferent forms. The method that seems to be the most satisfactory is to introduce a factor in the black body equations so that these equations will give the relation between radiation and temperature for the bodies studied. These factors are called emissivities and may be either given for a definite spectral region or for the total energy. The spectral emissivity may be a function of either the temperature or the wave-length. Such spectral emissivities as have been measured have been found to depend upon both the temperature and wave-length. The available data indicate that spectral emissivities for the visible spectrum are a linear function of the temperature within the error of measurement.

The brightness of the black body for any wave-length interval or for the total spectrum can be used as a measure of temperature. Starting with any known temperature any other temperature of a black body can be calculated from relative measurements either of the total brightness or the brightness of a particular spectral interval. Optical pyrometers have been constructed to measure the temperature of black bodies using a definite wave-length interval. These optical pyrometers, calibrated against the standard black body, are sometimes used to

[4] Ibid, *37*, p. 380; June 1913.
[5] Ibid, *37*, p. 164; April 1913.
[6] Bulletin Bureau Standards, *11*, p. 41; 1915.
[7] Astrophys. J., *37*, p. 194; April 1913.

measure the temperature of non-black bodies in terms of their brightness. Obviously, since the non-black body is not as bright as the black body for any wave-length interval or temperature, too low values will be obtained for the temperatures.

Suppose that an optical pyrometer is calibrated by comparison with a black body for a definite range of temperature. Now, if this calibrated optical pyrometer is used to measure the brightness of another black body, from these readings the true temperature may be obtained. Suppose that the pyrometer is sighted upon a non-black body and a reading obtained which, if obtained from a black body, would correspond to a temperature of 2000°K; this is not the true temperature of the non-black body but is lower than the true temperature, depending upon the radiation characteristerics of the metal studied. Temperatures thus obtained of non-black bodies are called brightness temperatures, and it is desired to know the relation between these brightness temperatures and the true temperatures. Suppose that the true temperature of the body investigated corresponding to this brightness temperature of 2000° is known. From Planck's equation and the brightness thus obtained, the following equation shows the relation between the temperature, the brightness, and the wave-length

$$E_\lambda \text{ (the brightness)} = \left(\frac{c_1\lambda^{-5}}{e^{c_2/\lambda T}-1}\right)_{bb} = \left(\frac{c_1\lambda^{-5}}{e^{c_2/\lambda S}-1}\right)_x = \left(\frac{e_\lambda c_1\lambda^{-5}}{e^{c_2/\lambda T_1}-1}\right)_x$$

where the term marked *bb* refers to the black body at temperature T, and the terms marked X refer to the non-black body at brightness temperature, S, and true temperature, T_1. The factor some as e_λ in the right-hand term is the emissivity of the non-black body at temperature T_1 and is the factor giving the relative brightness of the non-black body and the black body both at the same temperature, T_1. From these relations the relation between T_1 and S can be calculated if e_λ is known.

The total emissivity of a non-black body is the relation between total energy radiated by a black body and that radiated by a non-black body at the same temperature.

$$E = e_t \sigma T^4$$

where E is the total energy for a known temperature, T, and e_t the total emissivity.

From what has been said it will be evident that, if the spectral emissivities are known as a function of the temperature and the wave-length for any known substance, its radiating characteristics can be

completely worked out. Thus in most instances where it has been possible to do so the study of the radiating characteristics has consisted of the determination of the various emissivities.

The radiation from non-black bodies may be selective or may be gray. By selective radiation is meant one that radiates a larger proportion of its energy in a particular part of the spectrum than the black body does for the same temperature. A gray body and a black body radiate the same proportions of their energy in the different parts of the spectrum for the same temperature. Stated in terms of emissivity, the emissivity of a selective radiator is different for different parts of the spectrum, and the emissivity of a gray body is constant for the entire spectrum. Some very interesting mistakes have been made in interpreting and describing selective and gray radiating bodies.

FIG. 2. *Photograph showing Worthing's tungsten tube black body with pyrometer filament projected against small radial hole.*

Tungsten as a radiator has been much more extensively studied than any other metal. Data can be found for the radiating characteristics of tungsten for any temperature up to the melting point, and for a wide range of wave-lengths. A tungsten filament either of wire or ribbon, when mounted in vacuum or inert gas, can be heated up to any desired temperature up to a limit determined by the rate of vaporization of tungsten, and by maintaining a constant current through the filament a very constant temperature is obtained.

A great amount of work had been done on tungsten before a definite method was worked out for determining its true temperature. Worthing[8] built a black body of tungsten and thus was able to de-

[8] Phys. Rev., N.S., *10*, p. 377; Oct. 1917.

termine its spectral emissivity. The temperature was measured by observations on the black body, and the relative brightness of tungsten measured on the outside of the black body. The black body which Worthing constructed was made by pressing tungsten into the form of a tube about 2 mm in diameter with a central hole about .8 mm in diameter. He then made small radial holes somewhat less than .1 mm in diameter into the central cavity. The radiation as observed through these small holes from the inside of the tube satisfied the conditions for black body radiation, since it came from a cavity with uniformly heated walls having a very small opening for observation purposes. It was an easy matter to determine the temperature by observations through these small openings and also to measure the relative brightness of a black body and of tungsten by readings on the small holes and on the surface of the tungsten. This work assumed, of course, that the outside and inside of the tungsten tube were at the same temperature. Calculation using the known heat conductivity of tungsten for a tube electrically heated showed that even at high temperatures the difference was very small, amounting to only a few degrees at 3000°K. Corrections were made for this difference.

After the emissivity for a particular wave-length interval had been determined, thus making it possible to determine the true temperature, other radiation characteristics could readily be measured. These characteristics were determined separately for the three different parts of the spectrum. Worthing's work with his black body gave the foundation for the radiation characteristics in the visible spectrum. Hulburt[9] measured the emissivity of tungsten down to .34μ in the ultraviolet using tungsten in the form of a strip, 32 mm$\times$2 mm, calibrated for temperature. He used a spectrograph consisting of the Rowland mounting of a concave speculum-metal grating and a sodium photoelectric cell as the measuring device connected to a quadrant electrometer.

Weniger and Pfund,[10] using a fixed-arm type of spectrobolometer, measured the reflection factor of tungsten for a range of temperature from about 1400°K to 2000°K for a wave-length range from about .67μ up to about 4μ. They also checked these measurements with the tungsten at room temperature. The results obtained agree in general with other work on metals for the infrared. For wave-lengths near 2μ the results obtained by Weniger and Pfund agree well with results

[9] Astrophys. J., *45*, p. 149; April 1917.
[10] Phys. Rev., N.S., *14*, p. 427; Nov. 1919.

calculated by Drude's formula connecting the reflection factor, specific resistance and wave-length. Their work showed that for wave-lengths shorter than 1.27μ an increase in temperature causes an increase in reflection factor, and for longer wave-lenths the reverse is true. From the relation connecting reflection factor and emissivity, these values can be converted into emissivities for this infrared part of the spectrum. By comparing the results of Hulburt, Worthing, and Weniger and Pfund it is possible to calculate the distribution of energy from a tungsten filament for a range of wave-lengths from about .35μ up to about 4μ, at a temperature range up to 2100°K or higher.

The relative distribution of energy in the visible spectrum of various radiating bodies for different temperatures has long been a matter of interest. There are two methods for obtaining directly such relative distributions in the visible spectrum; the one is by using some form of a spectrophotometer where the comparisons are made by eye observations, the other by using one of the methods where the energy is compared by means of some type of energy measuring device.

Owing to the decreasing sensibility of the eye, observations with the spectrophotometer are very difficult at the extreme red or blue end of the spectrum. It is also very difficult to make accurate measurements with a bolometer or thermopile in the extreme blue end of the spectrum. Spectrophotometers using photoelectric cells are coming into use and seem quite promising.

A third method of obtaining such relative distributions, which has come into general use during the past few years, has someadvantages. This method consists in matching in color the light from the source studied with that from a black body or other standard source. Such comparisons can be very accurately made with the ordinary Lummer-Brodhun contrast photometer. To do this the source studied is mounted on one side of the photometer with a contrast comparison field and a comparison lamp on the other side. Suppose that at the start the comparison is too low; then when there is a brightness match the trapezoid that is illuminated by the comparison lamp will appear reddish as compared with the other, which appears bluish. If now the voltage applied to the comparison lamp is raised a small amount and at the same time the photometer moved so that there is an intensity match, as observed in the photometer, the comparison trapezoid will, if the change has not been too great, appear less reddish than be-

fore. By repeating this process the comparison lamp can be very accurately matched in color with the source being studied. The source being studied is now removed and replaced with the standard lamp and the process repeated just as before excepting that in this case the voltage applied to the standard lamp is varied and the comparison kept constant at the voltage above obtained. Thus the standard source can be brought to a color match with the comparison source. In this way the source studied and the standard lamp are color matched by the substitution method, which is supposed to eliminate errors due to the instrument. It has been found experimentally that a black body and most radiating solids can thus be color matched. Also most of the flames that have been used as light sources can be color matched with the black body. However, the Welsbach gas lamp and the sources that do not have a continuous spectrum cannot be so compared. For any source that can be color matched with the standard, the distribution of energy in the visible spectrum can be obtained much more accurately and with much less work than by either of the other methods, as will be shown below.

In order to see how different observers would agree in their setting, two lamps were color matched[11] by the substitution method by a number of observers. All the observers except one made three sets of five readings each on the voltage of the two lamps for color match with a third lamp of the same type held at a constant voltage.

In Table 2 are given the results of this test. The first three observers as listed in the table had had considerable experience with this kind of work. The fourth observer had had some previous experience, while the last two had had no previous experience. The color temperature of the lamps used in this and the following test was about 2400°K. The illumination on the photometer screen for this test was 5.1 foot candles. The averages of the voltages obtained in each set by each observer for lamp No. 4 to color match lamp No. 5 at 105 volts are given. There is also given the mean variation in volts for the different readings for the different observers. An examination of the table will show that the maximum range in the three sets for any of the experienced observers is less than 0.5 volt. The range in the averages of the three sets for these same observers is only about one tenth volt. The maximum range in the averages for all the observers is only about five tenths volt. A change of one volt at this point corresponds to a change

[11] J.O.S.A. & R.S.T., *6*, p. 476; July 1922.

in color temperature of about 8°K. It can thus be seen that the maximum range for inexperienced observers corresponds to about 4°K. A range of 4°K at this temperature corresponds to an error of about 0.6% in relative energy between the red ($\lambda = .665\mu$) and the blue ($\lambda = .467\mu$). This is much better than the accuracy generally claimed in spectral distribution work.

TABLE 2. *Values obtained for color matching lamp No. 5 against lamp No. 4 by a number of observers.*

Observer	Volts for color match mean of three readings	Mean of three sets	Mean variation in volts
F. E. C. 1	103.39		
2	.60		
3	.71	103.57	0.19
A. H. T. 1	103.72		
2	.71		
3	.66	103.69	0.25
W. E. F. 1	103.80		
2	.45		
3	.79	103.68	0.13
R. S. 1	103.78		
2	.47	103.63	0.31
R. D. 1	104.43		
2	103.30		
3	.51	103.75	0.20
I. K. 1	103.15		
2	103.49		
3	102.81	103.15	0.28

The photometer used in making the color matches is of the Lummer-Brodhun contrast type having a contrast of about eight per cent. The reason for using this type is because it has been found to be much easier to make color matches with a contrast photometer. However, such matches can be made with an ordinary equality of brightness photometer.

Comparison of color scale with that of the Bureau of Standards. A tungsten lamp was color matched against the color standards of this laboratory[12] and then sent to the Bureau of Standards, where it was

[12] Ibid, *6*, p. 481; July 1922.

color matched against their color standards by Priest. The lamp was then returned to this laboratory where it was again color matched. The Bureau of Standards also sent a high efficiency lamp to this laboratory for a like check. The results are given in Table 3.

TABLE 3. *Intercomparison of color scales.*

Lamp	Color temperature degrees Kelvin			
	Nela	Bureau of Standards	Nela	Bureau of Standards
900 watt movie	3091	3085	3083	
500 watt gas-filled			2848	2848

The good agreement obtained in the two laboratories by two different methods shows the agreement possible in such work.

If two sources so radiate that when they are color matched by the method outlined above they have the same spectral distribution to within errors of observation, such color matching can be obtained by measuring the relative brightnesses of the sources in two parts of the spectrum. If the two sources have the same relative distribution when color matched, the two curves that represent their energy distribution can be made to coincide exactly by changing the scale of one of them. The measurement of the relative brightnesses can be made with any form of spectrophotometer or with an optical pyrometer using as a monochromatic screen first a red and then a green, or first a red and then a blue, glass. To do this with a pyrometer it is more convenient to have the pyrometer calibrated for relative brightness rather than for temperature. Using the pyrometer thus calibrated the relative brightnesses corresponding to an interval in the red and an interval in the blue parts of the spectrum can be measured.

To determine the relation between red-blue ratios thus obtained and color temperature a series of such ratios were determined for a black body at different temperatures, which gave a series of ratios and the corresponding distribution in terms of the temperature of the black body. Comparing the brightness ratios of the black body with those obtained from the source being investigated, the color temperature of the source can be determined, under the assumption that the same relative brightnesses in these two parts of the spectrum mean the same color temperature.

A carbon lamp and a tantalum lamp were color matched with a tungsten color standard by the red-blue ratio method and also by

the method using a Lummer-Brodhun contrast photometer, for a range of temperatures, and results were obtained by the two methods that differed by only a degree or two at 2400°K. When two different radiators such as tungsten and carbon are color matched so that the integral color is the same there has been some question as to the extent to which they have the same distribution of energy in the visible spectrum. This was tested out with carbon, tungsten, and tantalum by Hyde[13] for a particular temperature. When the tungsten and tantalum lamps were color matched with the carbon lamp by the red-blue ratio method, as determined from spectrophotometric measurements, at .5μ and .9μ, it was found that the tungsten was about one-half per cent brighter in the green than the carbon, and the tantalum was about one per cent brighter than the carbon.

Later this test[14] for spectral distribution and color match was carried out for tungsten, tantalum, platinum, osmium and carbon as compared to the black body for a wide range of temperature by measurements made with an optical pyrometer using red, ($\lambda = .66\mu$), green ($\lambda = .57\mu$), and blue ($\lambda = .47\mu$) screens in the eyepiece. It was found that the carbon had practically the same distribution as a black body when they were color matched. The observations showed that tungsten radiated in such a manner that when its temperature is set to get the same red-blue ratio as a black body for a particular temperature, the green part of its spectrum was relatively brighter than that of a black body. This difference is small, being about one-half per cent for a color temperature of 1600°K and increasing to about one per cent for a color temperature of 2600°K. For tantalum the difference is in the same direction; that is, the green part is relatively brighter than a black body when tantalum has the same red-blue ratio. This difference is practically constant, equal to about one percent increase in brightness for the green part of the spectrum. The results for platinum are about the same as tungsten. Osmium, on the other hand, is relatively less bright in the green than a black body.

The red, green and blue brightnesses of the Welsbach mantle were also measured. The red-blue ratio thus obtained corresponded to a color temperature of about 2700°K for the Welsbach mantle. The measurements showed that for the mantle the green is about 30 per cent too bright for color match at this temperature. That is, if the curve that represents the spectral distribution of a black body at

[13] Astrophys. J., *36*, p. 114; Sept. 1912.
[14] J.O.S.A. & R.S.I., *7*, p. 1115; Dec. 1923.

2700°K and one that represents the spectral distribution of the Welsbach mantle be made equal for red and blue, they will differ in the green, where the intensity of the mantle will be about 30 per cent higher than the black body. In this case the actual brightnesses of the Welsbach mantle for the red and blue parts of the spectrum were only about 1/600 that of the black body at a temperature corresponding to this color temperature.

The great interest in tungsten is due for the most part to its value as a filament for incandescent lamps. Tungsten is the best material found for this purpose. It is selective in favor of the short wavelengths and can be operated at a very high temperature. Both of these properties make it valuable as a light source, since they both tend to give high efficiency. In Table 4 are shown the efficiency of some of the standard tungsten lamps and their mormal operating temperatures.

TABLE 4. *Temperature and efficiency of tungsten lamps.*

Volts	Watts	Type	Lumens/watt	Maximum temperature °K
115	15	Vacuum, inside frost	8.6	2470
"	25	" " "	9.5	2505
"	40	" " "	10.0	2535
"	50	Gas-filled, inside frost	10.2	2670
"	60	" " "	11.3	2695
"	100	" " "	13.4	2755
"	200	Gas-filled, clear	16.2	2865
"	300	" "	17.8	2915
"	500	" "	19.2	2965
"	1000	" "	21.7	3030
"	1000	Stereopticon	24.2	3185
30	900	Movie	27.3	3290
115	10-kw		31.0	3350
"	200	Daylight	10.0	2860
"	500	"	11.2	2960

The acetylene flame has been frequently employed in spectroradiometric work and has been subjected to investigation with respect to the distribution of energy in its spectrum as well as with respect to its constancy and reproducibility as a standard of luminous intensity. A study[15] was made to find out whether the distribution of energy in the visible spectrum of acetylene lamps as used in different labora-

[15] Phys. Rev., N.S., *14*, p. 379; Nov. 1919.

tories was the same, and also to find out whether any appreciable color difference would be observed when a black body was set at the nearest temperature to match the acetylene flame in color. In order to test this out a tungsten lamp calibrated as a color standard was sent to Jones of the Eastman Kodak Company and to Coblentz at the Bureau of Standards, with the request that they match it in color with their standard acetylene burners. They very kindly undertook to do this, and the lamp was returned and a check calibration made. A standard acetylene burner was also obtained from the Eastman Kodak Company and compared with the same standard tungsten lamp in the Research Laboratory at Nela Park. These three comparisons gave a result that differed only slightly more than 10°, with an average of about 2360°K for a color match of the particular acetylene flame used. Neither of the three laboratories reported any difficulty in color matching the acetylene flame with the standard tungsten lamp. Thus, the indications are that any differences in color between the acetylene flame and a black body are very slight. From the work on carbon filaments, since the light from the acetylene flame is doubtless produced from glowing carbon, one would expect practically no difference. In this investigation different acetylene burners were found to give quite different color temperatures, and also the purity of the acetylene and the completeness of combustion influenced the color temperature and intensity very appreciably.

In another investigation[16] the color temperature of quite a number of flames was investigated by comparing their color with the standard tungsten lamp. The gas flame with both batswing and candle-shape flame, the Hefner, pentane and kerosene lamps were investigated. In each instance it was found possible to color match these flames quite accurately with the standard tungsten lamps. In practically all of the flames the conditions of burning and form of burner had considerable influence on the color temperature of the source. The color temperatures of a number of such sources are shown in Table 5.

Mendenhall and Ingersoll[17] made a very extensive study of the radiating properties of the Nernst glower. They obtained their temperatures by melting small bits of substances on the Nernst glower, determining the point of melt by observations with a low power microscope. In this way they were able to study the radiating properties of the Nernst glower over a temperature range of several hundred de-

[16] Trans. Illum. Eng. Soc., *16*, p. 419; Nov. 1921.
[17] Phys. Rev., *25*, p. 1; July 1907.

grees, and then they were able to use the Nernst glower as a calibrated standard to determine other melting points. They also found that the radiation from the Nernst glower differed from that of a black body at the same temperature much more than even platinum. Later the Nernst glower was color matched against the laboratory standard of

TABLE 5. *Color temperature, brightness temperature, and brightness of various illuminants.*

Source	T_c	$S(\lambda = .665)$	Brightness c/cm²
Gas flame[1]			
Batswing	2160		
Candle shape about 10 cms high	1875		
Hefner as a whole	1880		
Candle			
Sperm	1930		
Paraffin	1925		
Pentane[2]			
10-cp std.	1920		
Kerosene			
Flat wick	2055	1500	1.27
Round wick	1920	1530	1.51
4 w.p.c. carbon	2080	2030	54.9
3.1 w.p.c. treated carbon	2165	2065	70.6
2.5 w.p.c. gem	2195	2130	78.1
2 w.p.c. osmium	2185	2035	60.8
2 w.p.c. tantalum	2260	2000	53.1
Acetylene as a whole[3]	2380		
One spot[3]	2465	1660	6.69
Mees burner	2360	1730	10.8
1.25 w.p.c. tungsten	2400	2150	125.0
2.3 w.p.c. Nernst	2400	2320	258.0
Sun[4]			
Outside atmosphere	6500		224000
At earth's surface	5600		165000

[1] Coal and water-gas mixture, approximately 600 b.t.u.
[2] Color matched by Bureau of Standards.
[3] Burner (no reflector) from auto headlight "prest-o-lite."
[4] Calculated from Abbot's data.

color temperature, and it was found that the relation between brightness temperature and color temperature behaved quite differently from that of the metals. The difference between brightness temperature and color temperature increased for a range of temperature up to about 2100°K, and from that on to as high a temperature as it was possible to carry the Nernst glower this relation decreased, so that

at a brighness temperature of about 2400°K there was less difference between the brightness temperature and the color temperature than at lower temperatures. This means that the radiating properties of the glower changed so that the relative amounts of blue radiation became less for higher temperatures.

Ives[18] and his coworkers made a very extensive study of the radiation from the gas mantle. In their work the temperature was determined by using thermocouples of varying sizes and extrapolating to zero thickness. Using various forms of apparatus they were able to determine the emissivity of these glowers under the conditions used for a wide range of wave-lengths for the temperatures thus obtained. They also measured the reflection factor of the glowing mantle and in this manner checked their emissivity values. They found that the normal operating temperature of the mantle that they were working with was about 1930°K. The various oxides studied reached quite different temperatures when made into mantles and exposed to the same gas flame. These temperatures varied from about 1930° for thorium oxide to 1690° for silicon dioxide.

At the temperature at which they worked the emissivity of thorium oxide was very low, being about 5 per cent, and almost constant through the visible spectrum. On the other hand, the emissivity for pure cerium at a temperature somewhat lower than that of thorium changed from about 80 per cent for the blue end of the spectrum to about 40 per cent in the red part of the spectrum. This emissivity of 40 per cent corresponds to a brightness temperature of about 1800°K for the true temperature, which is a somewhat higher value for the brightness temperature of the Welsbach glower than that found by direct measurements with the optical pyrometer. They studied the admixture of various oxides with thorium oxide in different percentages. Practically all the oxides they mixed with thorium oxide very greatly reduced its temperature when exposed to the same flame, even for small percentages. The worst case was uranium oxide, where a 6 per cent mixture reduced the temperature to about 1500°. This should be expected, as uranium oxide radiates so nearly like a black body.

A great deal has been said at times about the efficiency of the Welsbach mantle as a light source. There has been some misunderstanding about this, because as compared with modern light sources it is a very inefficient radiator from the standpoint of a source of light. To be

[18] J. Frank. Inst., *186*, p. 401; Oct. 1918.

sure, from the standpoint of the temperature of operation it is much more efficient than a tungsten lamp at the same temperature. However, one of the advantages of the tungsten lamp as a source of light is the fact that it can be operated at a high temperature, thus giving a very high efficiency. If attempts are made to operate the Welsbach mantle at a temperature much higher than that ordinarily used, the cerium vaporizes off and leaves the pure thorium which is a very poor radiator.

An attempt[19] was made to determine the emissive power of zirconium oxide, using three methods. (1) The oxide was heated on a platinum strip and its brightness measured with an optical pyrometer and the temperature of the oxide determined by means of brightness measurements on the platinum strip. The results obtained by this method did not agree very well because it was hard to be sure that the oxide was thick enough to completely cut off the radiation from the platinum, and at the same time, to be sure that the radiating surface of the oxide was at the same temperature as the platinum strip.

(2) The oxide was mixed with gum tragacanth and pressed into the form of hollow glowers. Before baking these glowers a small hole was punched through to this central cavity. This gave a black body in the form already described. Lead-in wires of either tungsten or platinum were fastened to the end of the glower and the glowers were again baked at a high temperature. After the glowers were baked it was found possible to heat them electrically by using a very high voltage, that is, about 3000 to 4000 volts, providing they were first heated to a bright red temperature with a blast lamp. With such glowers the true temperature was measured by observations on the central cavity through the small hole and the relative brightness by observations on the outside wall of the glower near the small hole. Glowers with two different wall thicknesses were used in an attempt to determine the difference in temperature between the inside and the outside of the glower, but due to non-uniformity in heating the results were not accurate enough to measure this difference in temperature.

(3) The oxide was melted by means of an arc between two small pieces of the glower and measurements were made of the brightness of the melted part of one glower and also of the brightness of the image of the molten part of the other end as seen reflected in the first molten drop. From these readings, both the brightness temperature and the

[19] Phys. Rev., *20*, p. 101; July 1922.

emissive power of the molten glower material could be determined. The average of several determinations gave 2465°K for the black body melting point of the zirconium oxide. A later determination of the black body melting point from another set of glowers gave 2495°K. All the values of the brightness temperatures were plotted against the corresponding true temperatures and a curve drawn through the points that corresponded to 12% as the emissivity. This curve fits the different points reasonably well.

A study was also made of the emissivity of very pure thorium oxide. The oxide was pressed into the form of small tubes about 4 cms long and 2 mm outer diameter, with an inner diameter of 1 mm. The tubes were heated by means of a number of gas flames using different kinds of gas. By properly adjusting the flame it was possible to obtain a very uniform temperature. These tubes were provided with small radial holes for observational purposes.

The radiation coming from the small holes is black-body radiation, that from the surface of the tubes is radiation which is characteristic of the substance studied.

It was found that for oxy-gas heating, the red ($\lambda = .665\mu$) emissivity was practically constant and equal to about 39%, and that the green emissivity changed from 42% for $T = 1400°K$ to about 39% for $T = 2200°K$. For the same range of temperature for this method of heating the blue emissive power changed from 52% to 42%. When heated with the air-gas flame the red emissive power changed from about 35% for a temperature of 1500°K to about 18% at 1900°K. For this same range of temperature the green emissive power changed from 37% to 23% and the blue from 35% to 15%.

The oxide was also heated by several other methods, including heating by means of a hot tungsten wire running through the tube, and the results were all in agreement with the results obtained with the oxy-hydrogen flame.

Recently the study of the radiation of various oxides has been undertaken. In this work thus far no method has been developed for determining the temperature but merely the characteristics of the radiation in the visible spectrum have been measured for different temperatures. The various oxides were heated by means of air-gas flames or an oxy-gas flame or by means of cathode bombardment. Samples were made by pressing the oxides into small pellets or buttons by means of a hydraulic press or by fusing them with the atomic hydrogen flame.

The fusing of the oxides with the atomic hydrogen flame was very kindly done at Schenectady by Hewlett.

Two optical pyrometers were sighted upon the same spot of the samples being heated and their relative brightnesses measured in the red and blue part of the spectrum, and then in the green part of the spectrum. As mentioned above, when studying the radiation from a black body and metals, the brightness in the red and blue parts of the spectrum were measured and from this the characteristics of their radiation determined. If one plots the difference log of the red brightness-log of the blue brightness against the reciprocal of the temperature a straight line should be obtained. It was found that for all the metals studied a similar straight line was obtained, but that all the metals radiated in such a way that they were bluer than the black body when they were set for the same red brightness.

This same method was applied to a study of the results obtained for the various oxides and other materials. No such regularity was found for these substances as was found for the metals. Some substances, in particular thorium and zirconium radiated differently when heated in different manners. There was some evidence of reduction of some of the oxides studied at high temperatures. Uranium oxide radiated relatively very much the same as a black body.

The first difficulty in studying the radiation of various substances can be overcome more easily than the second. That is, methods have been devised for heating different substances to high temperature. To measure the temperature is not so easy. Black bodies can be made of the substances studied, but this leads to errors due to the low heaf conductivity which results in large differences in temperatures betweet the inside and outside of the black bodies. Thermocouples can be used in some instances, but a good method of obtaining the temperature of various substances at high temperatures is one experimental detail that must be worked out in the future.

NELA RESEARCH LABORATORIES
CLEVELAND, OHIO.

NEW YORK MEETING OF THE OPTICAL SOCIETY OF AMERICA, FEBRUARY 24, 25, 1928.

Joint Meeting with the American Physical Society

A Joint Meeting of the Optical Society of America and the American Physical Society was held at Columbia University in New York City, February 24 and 25, 1928. There were sessions for the reading of scientific papers during the morning and afternoon of Friday February 24. In the evening of February 24 there were two special addresses by invitation:

(1) Recent Theories of the Atom, by Dr. W. F. G. Swann, Bartol Research Foundation.

(2) Demonstration of the Baron Sheba Fast Moving Pictures, Professor Alexander Klemin (represented by Mr. Otto Lunde), New York University.

On Saturday morning there was a joint session with the American Physical Society in the auditorium of the Bell Laboratories on West Street. In the half hour preceding the opening of the meeting of the Societies there was a demonstration of talking motion pictures showing the Vitaphone and Movietone and thus illustrating the synchronized recording and projection of sound from phonograph records and films.

The concluding special feature of the program was a *Demonstration of Television* under the direction of Dr. H. E. Ives of the Bell Laboratories. The demonstration afforded an opportunity to see both transmitting and receiving equipment in operation.

Abstracts of papers presented before the Optical Society at the various sessions are given in the following pages.

C. C. Bidwell, *Secretary.*

Meeting of the Executive Council of the Optical Society of America February 24, 1928.

A meeting of the Executive Council was called by President I. G. Priest at the Physics Building, Columbia University, February 24, 1928. These were present: I. G. Priest (presiding), C. C. Bidwell, W. E. Forsythe, P. D. Foote, L. A. Jones and Adolph Lomb.

The following business was transacted:

Announcement of the Frederick E. Ives Endowment

Dr. Priest announced the acceptance by the Council by mail ballot of a gift of $1,000 from Dr. Herbert E. Ives to found and endow a medal in honor of his father, Mr. Frederick E. Ives, to be awarded biennially for distinguished work in optics.

The appointment of the following Committee on Foundation of the Ives medal was confirmed by the Council:

H. E. Ives, Chairman
Charles Bittinger
Adolph Lomb
J. P. C. Southall

Dr. L. A. Jones was appointed to make an announcement of the Foundation of the Ives Medal at the meeting of the Optical Society on the evening of February 24.

The suggestion of a formal ceremony in connection with the annual meeting in Washington, accepting the gift and exhibiting the design of the medal was approved. The selection of Professor Simon P. Gage to give the address on this occasion was approved by the Council.

Special Committee on Photographic Standards of Intensity

The continuance of the Special Committee on Photographic Standards of Intensity was approved. The personnel of this Committee is as follows:

L. A. Jones, Chairman	A. C. Hardy
E. C. Crittenden	H. E. Ives
Raymond Davis	C. E. K. Mees
K. S. Gibson	A. G. Worthing

Representation at the International Congress of Photography

The question of representation of the Optical Society of America at the next International Congress of Photography was discussed. The matter was referred to the President for later reference to the Council by mail ballot.

Membership Campaign

A proposal for the inauguration of a membership campaign was made by Dr. Priest and approved by the Council. The printing of a booklet of general information concerning the Society for use in this campaign was approved. It was suggested that the booklet contain the Constitution and By-Laws, list of members and possibly tables of contents of one or more volumes of the Journal.

As a part of the campaign the Secretary was authorized to have mailed to non-members one thousand (1,000) copies of the advance program of the November 1928 meeting in Washington.

The President was authorized to appoint a special committee to estimate the justifiable and expedient expense of such a campaign. After this Committee's recommendation shall have been approved by the Council and specifically by the Treasurer the Membership Committee was authorized to proceed in accord with such recommendation.

The following Membership Committee was appointed and approved:

C. C. Bidwell, Chairman	Saul Dushman
A. F. Pfund	F. C. Brickwedde
A. E. O. Munsell	Charles Sheard
R. T. Birge	Frank Allen
A. C. Hardy	A. Ames, Jr.
M. Luckiesh	E. P. T. Tyndall
P. E. Klopsteg	H. M. Randall
H. G. Gale	Louise L. Sloan
J. P. C. Southall	H. G. Ott
C. W. Keuffel	H. P. Gage
F. K. Richtmyer	Henry Crew
Edison Pettit	L. R. Ingersoll
P. D. Foote	H. S. Uhler
L. A. Jones	L. O. Grondahl
W. B. Rayton	L. S. McDowell

Appointments Approved by the Council

The following appointments by the President were approved by the Council:

(a) Representative to the International Committee on Illumination: Frank Benford.

(b) Representatives to A.A.A.S.: H. E. Ives and F. K. Richtmyer.

Committees Approved by the Council

The following committees were appointed by the President and approved by the Council:

(a) Finance Committee:

Adolph Lomb (Chairman) — C. W. Keuffel
F. K. Richtmyer — J. P. C. Southall
P. D. Foote

(b) Publications Committee:

F. K. Richtmyer (Chairman) — J. P. C. Southall
P. D. Foote

(c) Committee on Contract with Scientific Instrument Makers' Association:

F. K. Richtmyer (Chairman) — Adolph Lomb
P. D. Foote — J. P. C. Southall

(d) Committee on Publication and Care of the Society's Official Records and Official Notices:

C. C. Bidwell (Chairman) — H. E. Ives
P. D. Foote — F. K. Richtmyer
Adolph Lomb — J. P. C. Southall

(e) Committee on Publication of Membership Directory:

C. C. Bidwell (Chairman) — F. K. Richtmyer
P. D. Foote — Adolph Lomb
H. D. Hubbard

(f) Special Committee on Transfer of Associate Members to Regular Membership:

C. C. Bidwell (Chairman) — K. T. Compton
H. E. Ives — L. T. Troland
A. H. Pfund — J. P. C. Southall
H. G. Gale — F. K. Richtmyer
W. T. Bovie — W. E. Forsythe

Washington Meeting

The dates for the Washington Meeting, November 1, 2 and 3, were approved.

An exhibit of instruments in connection with the Washington Meeting and a publication of a catalogue of exhibits, the cost of which shall be assessed on the exhibitors, was approved.

CHARLES C. BIDWELL, *Secretary*

1. Wm. G. Exton, M.D. Laboratory of the Prudential Insurance Company of America

THE SCOPOMETER: AN INSTRUMENT FOR MEASUREMENT AND ANALYSIS OF DISPERSIONS

Of several papers previously presented to the Society dealing with experiments in measuring turbidity, the last one (October, 1927) described an improved extinction method which, besides other advantages, gives values noticeably different from those obtained by diffuse density methods and nephelometry. These differences and an apparent change in opacity observed in some specimens when they are measured by different light effects point to a selectivity of light effect on the separate structural variables contributing to a turbidity. Thus particle size, shape, number, etc., seem each to be more sensitive to some and relatively insensitive to other light effects, and the possibilities of deriving information about dispersions by measuring the same sample by several different light effects, or optical methods, and correlating the results, seems not to have been hitherto appreciated. The present paper describes an instrument called the Scopometer which is designed to enable one to make extinction and photometric measurements rapidly and without disturbing the sample. Some applications of scopometry with illustrative data are suggested.

The present paper will appear in full in Jour. Am. Chem. Soc.

2. Raymond Davis and K. S. Gibson **Bureau of Standards**

FILTERS FOR THE REPRODUCTION OF SUNLIGHT AND THE DETERMINATION OF COLOR TEMPERATURE

Partial reports (cf. below) have previously been given. The investigation is now practically completed and may be outlined as follows:

For use in photographic sensitometry and colorimetry, a series of filters has been developed by which the spectral distribution of a Planckian radiator at any temperature from 2300° to 4000°K may be converted into a practical duplication of the spectral distribution of mean Washington noon sunlight.

By designing these filters so that they all give an exact color match with the adopted mean sunlight, in addition to a close energy match, they may also be used to calibrate the intensity and color temperature of any incandescent lamp above 2300°K, thus avoiding the troubles of heterochromatic photometry.

A second series of filters has been developed for converting the color of a Planckian radiator at 2848°K to that of any Planckian radiator between 3500° and 10,000°K.

Each filter consists of a two-compartment cell (three borosilicate crown glass plates), one compartment containing an aqueous pyridine-mannite solution of copper sulphate, the other an acidified aqueous solution of copper sulphate and cobalt ammonium sulphate. Each solution is one centimeter in thickness. The filters are all reproducible from specification and may be prepared in any laboratory.

Computations of the light transmission, in addition to the spectral distribution and color, have been made for all filters. The effect of variation of temperature has been investigated, and the permanence of the solutions tested over a year's time. These and other effects will be illustrated, and several direct experimental checks on the completed filters discussed.

Bibliography
Davis and Gibson, J.O S.A. & R.S.I., *14*, p. 135; February 1927.
Davis and Gibson, Phys. Rev. (2), *29*, p. 916; June 1927.
Report of O.S.A. Committee on the Unit of Photographic Intensity, J.O.S.A. & R.S.I., 12. pp. 570–75; June 1926.

The present paper will appear in full in B. S. Scientific Paper.

3. H. J. Reich (Introduced by F. Bedell) **Cornell University**

THE PHOTO-ELECTRIC EFFECT IN GLOW-DISCHARGE TUBES

The purpose of this investigation was a study of the change of discharge voltage of glow-discharge tubes with illumination, first described by Oschwald and Tarrant in Proc. Phys. Soc. of London 1924. The tubes used were of German manufacture and consisted of two glass bulbs about one centimeter in diameter, joined by a half centimeter tube two centimeters long, filled with either neon or helium. The electrodes were small pieces of aluminum fused to glass projections within the bulbs. Because of the change of characteristics as soon as a single sustained discharge took place after a period of rest, the discharge was made to occur periodically at a frequency of from 30 to 120 cycles. This was accomplished by shunting the tube with a small condenser, charged from B-batteries through the resistance of a saturated vacuum tube, and discharged periodically through the glow tube as soon as the potential became equal to the flash voltage of the tube. The tube was illuminated by monochromatic light of variable frequency and known intensity, and the change of discharge voltage was measured by means of a vacuum-tube voltmeter.

The experiments indicate:

(1) That the phenomenon is a photo-electric effect caused by small amounts of alkali metals in the electrodes and glass (disclosed by later examination).

(2) That there is no definite relation between the magnitude of the effect and the portion of the tube illuminated.

(3) That the change of voltage per unit of light intensity decreases with increase of light intensity or discharge frequency, probably because of the holding over of ionization between discharges.

The paper will appear in full in J.O S.A. & R.S.I.

4. **Christine Ladd-Franklid** **Columbia University**

ALTERNATIVE THEORIES TO ACCOUNT FOR THE REDDISH BLUE ARCS AND THE REDDISH BLUE GLOW OF THE RETINA

This phenomenon has already been shown at meetings of the Optical Society; my whole audience, sitting in a dark room, with a band of red light on a screen, sees not only the red band of light but also (2) a reddish blue glow around it, and, stretching out from it on both sides, (1) big blue arcs—the bigger the farther away one sits. (This shows that is is an entoptic phenomenon—one is "seeing" (1) certain optic nerve fibers which lie on the surface of the retina and (2) certain bipolar cells which surround the image of the red band.

It has been suggested, by Gertz and others, that this is due to

A. An excitation caused by the action of the red-band-stimulated fibers on (1) adjoining fibers, (2) ganglia, (3) rods and cones.

But it may also be due to (and this is my theory)

B. The action of emitted *light* on the light-sensitive substance in the rods and cones.

A (3) is a theory lately proposed by Dr. Hallowell Davis (*Science*, Jan. 20, 1928), who recognizes the impossibility of all the preceding hypotheses. A(1): It cannot be *fibers* that are involved, because *fibers*, coming from one knows not where, would not have the right "place-coefficients" (if, your leg being cut off at the knee, you pinch a nerve end, you get a sensation, not where you pinch, but in the toe or the heel). A(2): It cannot be ganglia, because the existence of an after-image proves that the light-sensitive substance in the rods and cones (the Sehstoff) must be involved. But it cannot be A(3) the *action current* that affects them, because a quite similar electric current (which also causes visual sensations when sent in from the outside) is followed by *no* residual image. Consequently, it can only be *light* (and this is my theory) that this Sehstoff is affected.

The *argument* involved in this is so complicated, and at the same time so definite, that it might well be preserved as a classical case of scientific reasoning.

5. **Elmer A. Harrington** **Bureau of Standards**

A NEW REGISTERING PHOTODENSITOMETER

A direct-reading, self-recording densitometer with single thermocouple and low-resistance D'Arsonval galvanometer has been constructed and used to measure the relative opacities of the photographic images of the lines in ordinary spectra and in x-ray powder photographs. By suitable gearing to an electric motor the photographic negative is given a slow motion at right angles to a beam of light passing through a horizontal lens system; and at the same time a drum carrying photographic paper, on which a spot of light from the galvanometer is focused, is caused by the same motor to rotate at such a rate that a certain distance on the drum corresponds to a certain distance on the negative. A permanent record of the true distribution of opacities is thus obtained, since the deflections of the galvanometer are inversely proportional to the opacities on the negative.

Preliminary experiments show that the apparatus is dead beat and quick in response; and that it is sensitive, stable, and accurate.

The paper will appear in full in J.O.S.A. & R.S.I.

6. **H. J. McNicholas** **Bureau of Standards**

EQUIPMENT FOR ROUTINE SPECTRAL TRANSMISSION AND REFLECTION MEASUREMENTS

This paper gives a description of an assembly of apparatus which has been in use at the Bureau of Standards since August, 1924, for routine spectral transmission and reflection measurements. The Koenig-Martens spectrophotometer is used with different light sources, each source being designed especially to meet the desired conditions of illumination on the sample in the measurement of the following quantities as function of wave length:

(1) The unidirectional normal *transmission* of optically homogeneous (non-scattering) materials in the form of a plate with plane parallel surfaces.

(2) *The normal brightness of a sample by reflected light, relative to the same for a standard material*, when both sample and standard are under equal, and completely diffused, illuminations.

The sources for transmission measurements are three separate white-lined enclosures, each just large enough to contain, respectively, two 400-watt gas-filled incandescent lamps, two helium lamps, and a quartz mercury-vapor lamp. These sources are conveniently and quickly interchangeable.

A uniform distribution of 156 small gas-filled incandescent lamps on a white diffusely reflecting hemispherical surface provides a source of illumination for reflection measurements which tests have shown to be equivalent (for practical purposes) to the desired ideal completely diffused condition.

Accessory equipment includes ventilation apparatus, convenient devices for handling the transmission and reflection samples, standard sectored discs for use with the spectrophotometer, and apparatus for temperature control of liquid transmission samples.

The theory of the Koenig-Martens spectrophotometer is given, along with a discussion of some possible sources of error in the spectrophotometric measurements. Tests of the accuracy in the measurement of the specified quantities are described.

The present paper will appear in full in B. S. Scientific Paper.

7. F. E. Wright **Geophysical Laboratory**

THE SOLUTION OF PROBLEMS IN ELLIPTICALLY POLARIZED LIGHT WITH THE AID OF A SPHERICAL PROJECTION CHART

Poincaré showed in 1892 how the relations in elliptically polarized light can be solved graphically by reference to a sphere or to a stereographic projection. His method has been successfully applied by a number of workers in this field. It has been found by the writer that the use of a specially prepared angle or stereographic projection chart as a base greatly facilitates the graphical solutions, provided that a method of approach is adopted that differs somewhat from the usual methods. A brief description of this method as applied to the derivation of the projection equations and to the solution of problems in elliptic vibrations is presented.

The paper will appear in full in the J.O.S.A. & R.S.I

8. George B. Welch (Introduced by Ernest Merritt) **Cornell University**

THE NUMBER OF DISCRIMINABLE COLORS

Using the Titchener-Ebbinghaus color pyramid as the psychological color solid and the experimental results of Konig, Geissler, and Jones on brilliance, saturation, and hue, certain simplifying assumptions are made and the total number of discriminable colors is computed. The result is slightly over two millions.

The present paper will appear in full in J.O.S.A. & R.S.I.

9. Richard Hamer, Charles Lithgow and C. J. Cardin **Pittsburgh, Pa.**

INVESTIGATION OF ARCING POTENTIALS OF MERCURY VAPOR ILLUMINATED BY FULL ULTRA-VIOLET RADIATION OF ANOTHER ARC

This experiment was devised in an attempt to determine the relative importance of the radiation factor in arcing vapors. A horizontal pyrex tube 3 cm. diam. and 150 cms. long was built up with two arcing chambers one at each end connected with mercury reservoirs below. By means of an inner projecting tube and two reservoirs an intense mercury arc could be struck at one end, thus directing a beam of extreme ultra-violet radiation down the long tube. The other end was expanded into a bulb enclosing an iron disc electrode below surrounded by mercury with a tungsten filament above it suspended from a ground joint. An electric furnace surrounded the bulb. There was no obstruction whatever in the long connecting tube but two cold water condensers between prevented mercury vapor passing over from the arc to the other region.

The potentials necessary for striking and maintaining an arc were determined first without and then with the intervening vapor between filament and positive electrode illuminated by the full ultra-violet radiation from the other arc. No marked effect was observed especially when a ballistic galvanometer was used for measuring the plate current. With higher temperatures and lower striking potentials occasionally there seemed indications of a reduction of about two volts. Even exposing the iron electrode or the tungsten filament to the radiation had no very appreciable effect in this preliminary work but permitting ions to drift over usually caused an arc to strike at once.

The bearing of these observations on the theory of arc formation and maintenace is briefly discussed. Evidently ultra-violet light quanta are somewhat inefficient as ionizing agents or else they do not readily penetrate the two boundaries of condensing mercury vapor.

10. Otto Sandvik and George Silberstein **Eastman Kodak Co.**

THE DEPENDENCE OF THE RESOLVING POWER OF A PHOTOGRAPHIC MATERIAL ON THE WAVE-LENGTH OF LIGHT

The resolving power of six different emulsions has been investigated. The spectral region covered extends from wave-length 380 $m\mu$ towards the red end of the spectrum as far as the sensitivity of the particular emulsion would permit. The resolving power has a maximum value at wave-length 380 decreasing rapidly in the glue-green to a minimum value at about wave-length 535 $m\mu$.

It is interesting to note that the change in resolving power with the wave-length corresponds approximately with the change in the absorption coefficient with the wave-length in the spectral region investigated.

11. Richard Hamer **Pittsburgh, Pa.**

THE SUGGESTED APPLICATION OF ULTRA-MICRONIC OSCILLATING CIRCUITS TO NEW ETHER DRIFT EXPERIMENTS

Dr. Miller's small but definite positive result for the Michelson Morley experiment which was interpreted as a reduced ether drift of 10 km/sec and the result of Kennedy and Illingworth yielding no drift greater than possibly 1 km/sec taken together leave doubt as to the reality of a drift.

Some other distinct method should be applied to this important problem. The great development in the use of oscillating circuits should make it possible to secure now a sensitivity of about one part in 10^8 at least and permit testing the effect of a possible Fitzgerald-Lorentz contraction on the capacity of a parallel plate condenser or on the inductance of the coil of a high frequency oscillating circuit. These can be rotated about different axes in space into the direction of the supposed ether drift. Formulas have been derived for various combinations.

The possibility is discussed of the apparent compensation of the light path in the Michelson Morley experiment being due to variations in the dielectric or permeability values of the ether instead of the Lorentz-Fitzgerald contraction of the apparatus.

These suggested tests should determine on the classical basis if the ether, whether considered streaming or stationary, is isotropic or not as regards either of its permeability or dielectric values.

JOURNAL OF THE OPTICAL SOCIETY OF AMERICA AND REVIEW OF SCIENTIFIC INSTRUMENTS; FINANCIAL REPORT

FOR THE PERIOD FROM JANUARY 1, 1927 TO DECEMBER 31, 1927

RECEIPTS

Cash on hand January 1, 1927		$ 2,606.55
In account with the Optical Society of America		4,800.00
In account with the Association of Scientific Apparatus Makers of America—Advertising		7,631.87
Miscellaneous Receipts		
Subscriptions	$3,221.17	
Sale of back numbers	458.29	
Reimbursements	31.54	3,711.00
Total		$18,749.42

DISBURSEMENTS

Printer	$9,284.46	
Salaries and Office Expenses	4,870.93	
Miscellaneous	65.37	$14,220.76
Cash on hand December 31, 1927		4,528.66
Total		$18,749.42

The above is a correct statement of accounts to the best of my knowledge and belief.

(Signed) F. K. RICHTMYER, Business Manager
(Per C. M. Terry)

We, the undersigned, duly appointed to audit the accounts of the Journal of the Optical Society of America and Review of Scientific Instruments as at the close of business, December 31, 1927, hereby certify that we have examined the statement of receipts and disbursements, the vouchers, check book and bank book and find them to agree with each other. We, therefore, certify that the above statement is a true statement of the accounts of the Journal of the Optical Society of America and Review of Scientific Instruments as of December 31, 1927.

(*Signed*) H. E. HOWE
H. R. CHILDS
Auditors

OPTICAL SOCIETY OF AMERICA

FINANCIAL REPORT

FOR THE PERIOD FROM JANUARY 1, 1927 TO DECEMBER 31, 1927

CASH ON HAND, JANUARY 1, 1927		$12,421.75
RECEIPTS:		
Dues	$3,172.50	
Donations	3,000.00	
Interest on Bank Balances	393.39	
Journal Subscriptions on Books Prior to February 15, 1922	212.50	

Advertising	353.00	
Sale of Back Numbers	272.05	
Sale of Colorimetry Reports	8.50	
Miscellaneous	.30	
Total Receipts		7,412.24
		$19,833.99

DISBURSEMENTS:

Printing and Stationery	$ 68.22	
Postage	41.00	
Expenses of Meetings	205.09	
Journal Subscriptions Since February 15, 1922	174.25	
Traveling	42.64	
Clerical Expense	20.00	
Journal of the Optical Society of America and Review of Scientific Instruments, as per contract with the Association of Scientific Apparatus Makers of the United States	4,800.00	
Purchase of Bonds	4,956.25	
Accrued Interest on Bonds Purchased	32.22	
Miscellaneous	113.98	
Total Disbursements		$10,453.65
CASH ON HAND, DECEMBER 31, 1927		9,380.34
		$19,833.99

I certify that the above report is correct to the best of my knowledge and belief.

ADOLPH LOMB
Treasurer

Rochester, New York
January 19, 1928

Adolph Lomb, Treasurer,
Optical Society of America,
Rochester, New York.

Dear Sir:

In accordance with your request, we have audited the books of the Optical Society of America for the twelve months ended December 31, 1927.

We hereby certify that the above Statement of Cash Receipts and Disbursements is a true statement for the period from January 1, 1927 to December 31, 1927.

Respectfully submitted,

NARAMORE, NILSE CO.
Auditors

Physics in Industry. Volume V. By H. E. Wimperis, O.B.E., M.A., F.R.Ae.S., and F. E. Smith, C.B., C.B.E., D.Sc., F.R.S. Pp. 54 with 5 illustrations. (London: Oxford University Press, 1927.)

This little volume contains the tenth and the eleventh lectures on the general subject of Physics in Industry delivered before the Institute of Physics. The first of these lectures is by H. E. Wimperis on the "Relation of Physics to Aeronautical Science." The author deals with a great many different problems which have arisen in connection with the design of aircraft. "Aviation is now entering upon a new and intensely interesting phase—one which will call for every scientific resource at our command. The materials of construction are changing: wood is giving place to metal. The engine proves to have most unexpected possibilities ahead of it, through the increase of intake pressure; whilst the very lufting structure itself promises to change, for some purposes at least, from linear motion to rotary."

Among the subjects discussed are the flow around aerofoils; the fluid forces brought into play; the rotating wing as distinct from the fixed wing; the relation of tests in wind channels to full scale tests on aircraft; the testing of seaplanes in tanks designed originally for testing ship models; the aero engine; and the use of different anti-knock substances in engines; the effect of variation in atmospheric pressure and the use of artificial atmosphere of increased density.

The author makes this significant statement near the close: "For the world of physicists in general, aeronautics teems with problems of great complexity and intense interest which await their study."

In the second or eleventh lecture—"Physics in Navigation" by F. E. Smith the author gives a brief historical summary of some of the great contributions to navigation and then discusses briefly such subjects as measurements of latitude; measurements of longitude; magnetic compass; the gyroscopic compass; measurements of speed; sounding; position-finding; directional wireless; duplex fog signals; and ice fields. Of necessity each subject is briefly discussed but the essential technical problems of interest to the physicist are clearly defined.

Both of these lectures should prove of extreme value not only to the research physicist, as they indicate in a striking manner what has been accomplished and the fields that are yet to be explored, but to the teacher because they contain a wealth of material which can be used to illustrate the fundamental principles of physics and its application to industry.

The authors have made a real contribution to the increasing interest which is being developed concerning physics in industry.

F. L. BISHOP

INSTRUMENT SECTION

SOME EXPERIMENTS ON GEIGER ION COUNTERS

By Ralph D. Bennett[1]

ABSTRACT

With the purpose of extending the usefulness and reliability of the Geiger ion counter an investigation of its behavior under widely varying conditions was undertaken, including the effect of size of point and chamber, position of point in chamber, effect of voltage on sensitivity, effect of nature and pressure of gas used, sensitivity to ultraviolet light, sensitivity to ions of small energy, effect of various properties of the electrical circuits, and an investigation of the time lag in its action.

It is concluded that the counter is a very sensitive instrument for detecting single ions; that it is only a moderately sensitive detector of ultraviolet light because of low efficiency; that it is primarily a qualitative instrument, though of possible quantitative use subject to the difficulty of keeping the sensitivity constant over the long periods necessary to take statistical averages. Some surmises are made as to the manner of its action.

INTRODUCTION

A Geiger ionization counter consists of a chamber filled with gas within which can be inserted a point electrode, more or less sharp, this electrode being insulated from the chamber. Upon application of a proper potential between chamber and electrode, discharges occur when certain radiations are admitted to the chamber. The writer has found it most convenient to use cylindrical chambers, usually of brass, of from 0.5 to 10 cm diameter, sometimes with ends open, at others closed either with a dielectric or a conductor. The point is usually inserted through a sealing wax or hard rubber plug in the opposite end, and a guard ring is not generally necessary. The counter can be excited by α, β, γ, X and untraviolet radiations, and by electrons or positive ions blown into the chamber with gas, or drawn in from a hot filament. The geometric shape of the electrodes is such that when potential is applied an intense converging electrostatic field is produced about the point. An electron traveling through this field gains sufficient velocity to produce ions by collision, making a cumulative effect which is sufficiently large to be detected by means of a vacuum tube amplifier or other sensitive device. The purpose of the varied experiments recorded below was to extend the usefulness and reliability of the instrument.

APPARATUS AND METHOD

The amplifier used was of the resistance coupled type having three stages, the first two tubes having amplification constants of about 30,

the last a power tube of amplification constant 6, working into a loud speaker or chronograph relay. Part of the time the high voltage source consisted of a motor-generator driven from storage batteries and in series with a high voltage battery, the combination giving up to 4000 volts. Later a rectifier and filter were used. The a.c. coming from a rotary converter, driven from storage batteries, was rectified and then smoothed by about 10 M.F. of condensers, this arrangement giving up to 10,000 volts. The fluctuation in voltage in either source was less than 0.1%. Voltage was measured either by a high resistance voltmeter or a milliammeter in series with a metallic resistance of 4 megohms.

Whether or not the counter functions properly depends almost entirely on the shape and condition of the point electrode. In earlier work done by the writer in Ryerson Laboratory at Chicago in 1924[2] ball points were found to be far more satisfactory than sharp points, and in the present work ball points only were used. Metals other than platinum can be used for the point but it is the most satisfactory, probably because it can be heated to high temperatures in air without oxidation.

To make a point[2,3] about 1.5 cm of platinum wire of about .4 mm diameter is mounted in the end of a supporting rod of metal. Soldering into a slit is a convenient way. This is ground to a point on a grinding wheel of moderately fine grain. The sharpened point is then put into a gas-oxygen flame until it is rounded or melts into a ball. (See Fig. 1). The voltage at which the point becomes sensitive de-

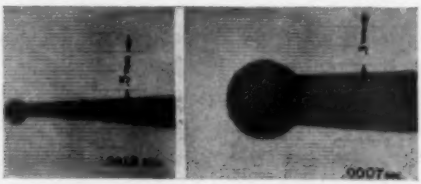

FIG. 1.

pends on the size of this ball. When viewed under a microscope this ball shows a brilliant polish, and the point usually will not function satisfactorily unless this surface remains unblemished. Not every point will function properly, even though the surface shows no blemish. Another method is to mount a section of very fine platinum wire in a supporting rod and simply melt the end into the necessary ball.

To test the point it is inserted into the chamber and connected to the detecting device and the voltage applied, starting at a low value, the point being negative with respect to the chamber. The source of radiation should be in a position to excite the counter. A convenient radioactive source is a bit of the radioactive paint taken from the face of a "Radiolite" clock, the rays entering the chamber through a thin window of mica or aluminum. Ultraviolet light may be used provided the chamber is open or equipped with a quartz window. A yellow gas flame a few centimeters high and 10 to 20 cm from the chamber makes a convenient source. As the potential is raised a value will be reached, probably between 1500 and 3500 volts where sharp clicks will be heard in the loud speaker. The value of potential at which these clicks begin is very sharp and definite,—the very first discharges being loud and strong—distinctly not a gradual increase in loudness. As the potential is raised the discharges will increase greatly in number and somewhat in intensity. Increasing the potential still further causes the short sharp discharges to be drawn out into hisses, and finally a continuous discharge occurs,[4] the point being surrounded by brush discharge, which if continued may under certain conditions pit and ruin the point. The active range varies markedly with different points for no very definite reason, but in general the higher the voltage at which action begins, the greater the range will be. Frequently it is 25% or more of the total voltage. In the most frequent form of failure of the point, the discharges do not cease when the source of excitation is removed.

If the chamber is made negative with respect to the point, the voltage at which registration starts is usually different. (See Fig. 2) The sounds in the loud speaker are very much weaker and would be entirely inaudible without considerable amplification. Many of the methods of detection used, such as telephone receivers,[5,6] electroscopes,[5] audible resonance,[7] electrometer,[8] string electrometer,[9] and galvanometer[10] might be insufficiently sensitive or rapid to detect these discharges, for they are barely audible with high amplification. The counter seems to be much more sensitive to gamma rays when used in this manner, but the active range is exceedingly short, being about 1% of the total voltage used, thus making a counter in this condition rather difficult to use. Unless otherwise specified in this paper, the point was negative with respect to the chamber.

All workers with counters find a certain number of strays, i.e., discharges without evident means of excitation. These increase in num-

ber if the point is exposed to the air of the room, until the point becomes useless, probably because of contamination of the surface by dust particles. Occasionally such particles can be seen with the aid of a microscope. Points have been made and used in closed chambers giving no strays in a half hour, which is sufficiently good for practical use. The strays seem to be mostly due to imperfections in the point, but may be partly due to ionization from some of the natural causes.

DEPENDENCE OF WORKING VOLTAGE ON SIZE OF POINT

Fig. 2 shows the variation of the voltage at which action begins with the diameter of the ball. The chamber used in making these

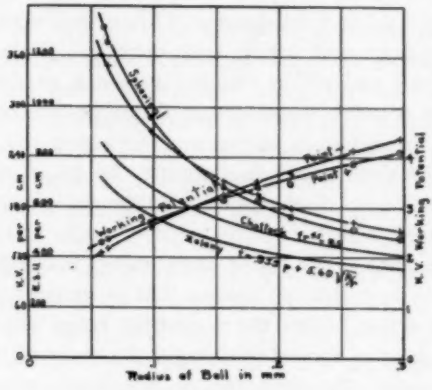

FIG. 2.

curves was a cylinder with a hemispherical end, the ball point being carefully placed at the center of the hemisphere. The electric intensities were then calculated, on the assumption that the field distribution over the ball was the same as that between concentric spheres, the exact calculation being exceedingly difficult if not impossible. This obviously will give a value which is too high but the general shape of the curve is much the same as those found by Zeleny[13] and Chattock.[14] Their measurements were made under considerably different conditions as regards shape of electrodes and amount of current flowing. The increase in field strength necessary to produce registration with decrease in size of point is probably due to the nature of ionization by collision as explained by Zeleny.[13] He concludes that not only must there be a certain minimum field strength to produce ionization by collision, but that also this field strength must exist throughout a considerable volume, because of the fact that probability con-

siderations enter into the process, making it necessary to have a certain minimum number of molecules present in the region of intense field.

The voltage at which a point is active depends also upon the size of the chamber, whether the end is closed with a conductor or non-conductor, and the position of the point in the chamber. Chambers have been used successfully from 0.5 cm diameter to no chamber at all, the walls of the room serving as the other electrode. Chambers made of wire screen also serve, but with all open chambers there is danger of contamination of the point by dust. The fact that the counters work with no end plate[11] and with no chamber at all is definitely contrary to the layer theory of Kutzner.[12]

EFFECT OF SIZE OF CHAMBER AND POSITION OF POINT

Fig. 3 shows the variation of potential at which the point begins to be active for a given point in chambers of different sizes. The rela-

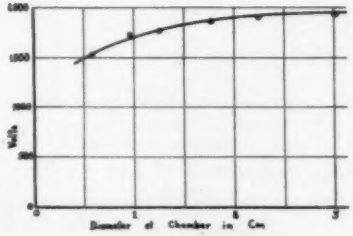

FIG. 3.

tive position of the point was the same in each chamber, namely a distance from the open end equal to the diameter. Whether or not the point is accurately centered axially in a cylindrical chamber has little effect on the working voltage shown by Fig. 4. The working

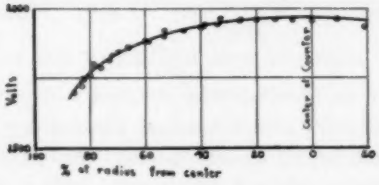

FIG. 4.

voltage depends on the distance of the point from the front of the chamber as shown by Fig. 5.

DEPENDENCE OF SENSITIVITY ON VOLTAGE

The sensitivity of the counter depends markedly upon the voltage applied,[15] a fact which renders it difficult to use the counter for quanti-

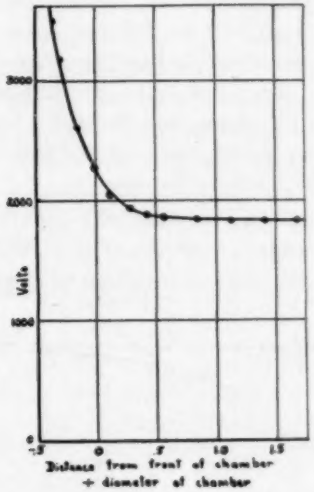

FIG. 5.

tative work unless a very steady source of potential is available. Fig. 6 shows a group of curves illustrating this point. With the source of excitation constant the number of registrations may vary several hundred per cent between the lower and upper parts of the working range. The best region in which to use the counter for quantitative work is just at the upper knee of the sensitivity curve. Stray disturbances increase rapidly above this point. The shape of these curves is somewhat different from those found by Geiger[16] for sharp point counters.

EFFECT OF PRESSURE AND NATURE OF GAS IN CHAMBER

It was hoped that the potential necessary to operate the counter might be materially reduced by use of gases other than air. Fig. 7 shows the relation between gas pressure and working voltage for several gases.[17] Since different points were used in each gas the voltages were reduced to a basis for comparison by multiplying each voltage by a factor which was the ratio of the voltage at which the point used in air worked at atmospheric pressure to the voltage at

which the point used in the particular gas worked at atmospheric pressure. Air and commercial hydrogen have proved most practical of the gases tried. None of these gases works well at less than 2 or 3 cms pressure.

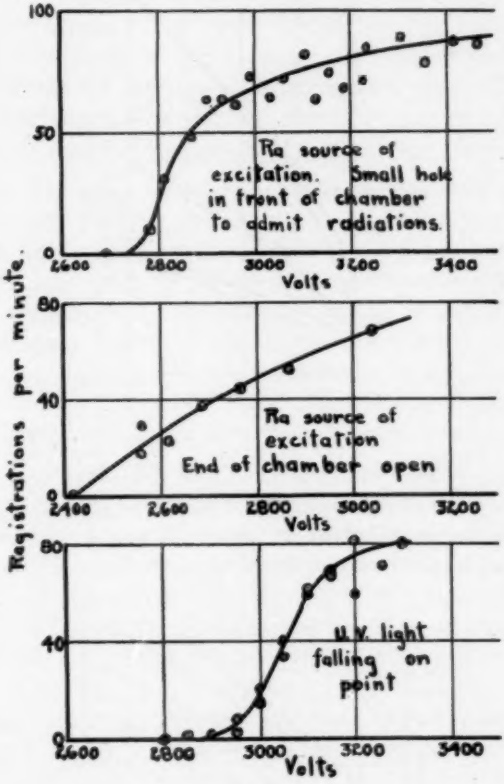

FIG. 6.

If hydrogen is purified by passing it through activated charcoal cooled with liquid air the first discharge started always continues, making the counter quite useless. If the discharge is continued the point soon becomes badly pitted and is no longer sensitive. Helium behaves very much as pure hydrogen, except that the starting potential is somewhat lower. Mixing with pure hydrogen does not im-

prove the action, but with commercial hydrogen does, and a mixture of about 10% commercial hydrogen with helium acts rather well and at a lower voltage than the hydrogen alone. The useful constit-

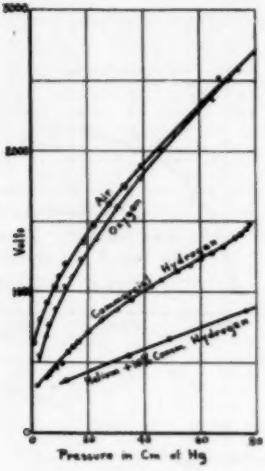

FIG. 7.

uent of the commercial hydrogen was not definitely determined, but it was not condensed out at liquid air temperature.

Nitrogen behaves as helium in that discharge once started will not stop itself, at least at any pressure between 2 and 76 cm, but for a

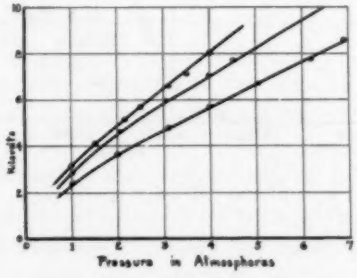

FIG. 8.

given pressure, the voltage necessary to start a discharge was higher than in either helium or hydrogen. In any of these gases in the pure state if the counter is unexcited, the voltage can be raised to from

1.5 to 2 times the value at which a discharge starts when excited, before breakdown occurs. Oxygen behaves very nearly like air.

When the pressure of the gas is lowered and consequently the potential at which action begins, there is no very noticeable reduction in the intensity of the discharges. Counters were tried in air up to a pressure of 7 atmospheres. The voltage at which counting began is plotted against pressure in Fig. 8. There was no marked change in the general behavior of the counter under higher pressures, indicating that counters working under very high pressures might be used advantageously in detecting γ-rays or hard x-rays.

EFFECT OF TEMPERATURE AND MAGNETIC FIELD

An attempt was made to determine whether high or low temperatures had any effect on the counter. Cooling with liquid air caused frost to be deposited on the point and it was not found easily possible to dry the air sufficiently to prevent this. A chamber was equipped with a heating winding. The working voltage is slightly lower at higher temperatures but the action is very much impaired, the number of strays increased greatly, the range shortened and the point soon ruined, even after a rise of 100°. The only effect of a magnetic field seems to be to raise slightly the voltage at which the counter functions.[18]

DETECTION OF IONS OF LOW ENERGY

Ions from a hot filament excite the counter. In this arrangement the chamber was usually connected with the amplifier and the filament kept at ground potential. When the point was made negative and the filament raised to a sufficiently high temperature the counter registered. Discharges began when the platinum filament reached about 550° these being due to positive ions. They increase in number enormously as the temperature is raised. If the polarity is reversed the discharges are the usual very weak ones detected when the point is positive with respect to the chamber. They first occur with the filament at a temperature somewhat higher than for positive ions and increase rapidly as the temperature is raised.

The counter was excited by blowing ions in bodily with gas. The ions were produced either with a spark or a hot filament in the gas stream. Air was blown through cotton wool, then through a chamber containing electrodes for sparking, then a chamber containing parallel plates to which a potential could be applied for removing ions, and finally into the counter chamber. An induction coil spark between copper electrodes produced a very violent effect from which the

counter did not usually recover. When the spark passed between platinum electrodes the effect was much less violent and not so destructive to the counter. 200 volts on the plates in the second chamber was sufficient to prevent any ions being recorded by the counter. A hot filament in place of the spark produced a similar though less violent effect.

EXPERIMENTS WITH ULTRAVIOLET LIGHT

In an attempt to get away from strays by raising a counter a considerable distance above the ground on a framework outside the building, it was noticed that the number of strays decreased when a cloud obscured the sun. It was at once suspected that solar radiation might be the cause, and it was found that a gas or other flame, quartz mercury lamp or electric arc have the same effect, provided glass was not placed between the counter and source. A quartz prism spectrometer was set up, and the counter was equipped with a slit which with the counter could be moved across the focal plane of the spectrometer. The principal ultraviolet lines from the mercury lamp were easily detected by this means.

To determine the long wave length limit a monochromator reading directly in a.u. was used, the counter being placed in front of its output slit. Two curves with registrations per half minute plotted against wave length are shown in Fig. 9. The carbon arc source gave

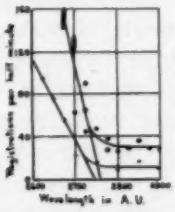

FIG. 9.

a sufficiently continuous spectrum for this purpose. The monochromator gave a considerable amount of scattered light of all wave lengths which accounts for the large number of strays beyond the long wave length limit. The limit is about 2750 A.U. which corresponds to a work function of 4.5 volts for platinum under these conditions. This is nearly that found by other methods and leads to the belief that ultraviolet light is detected by its power to remove electrons from the surface of the point.

To determine what part of the ball point was most effective, a slit

source was set up before a carbon arc. 150 cm away was placed another slit of .006 mm width and the counter of .64 mm diameter about 25 mm behind this slit, was moved across the beam of light which came through. The point showed maximum sensitivity at the center, falling off gradually toward the edges and showing no sensitivity at all to light which enters the chamber but does not strike the point. However, if the polarity is reversed, making the chamber negative, the counter responds to light striking the walls in the characteristic fashion for this polarity, the sensitivity being greatest slightly ahead of the point and falling off at the front and back.

An exploration of interference fringes was undertaken. A slit before a carbon arc was used as source. Next came a double slit and quartz lens, then the counter mounted on a micrometer screw at a suitable distance. The fringes were essentially white light fringes the interfering band extending from the lower limit for the carbon arc to about 2750 A. U. the upper limit for the counter The double slit was made by ruling two lines on a quartz plate sputtered with a heavy coat of platinum. The width of the lines was .043 mm and distance between centers was .126 mm. With this arrangement it was easily possible to get fringes up to 1 cm wide in the visible. Fig. 10 shows intensity

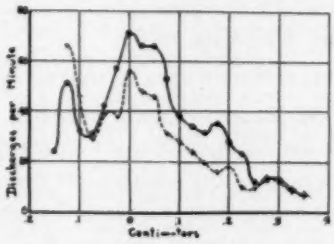

FIG. 10.

curves taken with this arrangement, each point on the curve representing a rate obtained by measuring the time required to register 50 discharges. Several hours elapsed between the taking of the two curves, but they agree rather well regards position of peaks. The asymmetry of the central fringe was noticeable in the visible. It would seem from this that interfering quanta lose their photo-electric power where neutralization of intensity occurs. The sensitivity of the counter for this work is not so high as a photographic plate and the method is much more complicated and laborious.

A measurement was made to determine whether a large percentage of the photo-electrons released was recorded. To this end the photo-electric emission was measured from a sputtered platinum plate in air using a carbon arc source. Correcting for relative intensities of light and for relative areas it was found that the number recorded per second by the counter was of the same order of magnitude as would be expected from the photo-electric measurements. However, the efficiency of the counter when used as a detector of ultraviolet light is low, even if nearly every photo-electron released is recorded. The surface of the point has such a brilliant polish that a large percentage of the light is reflected.

SENSITIZATION TO VISIBLE LIGHT

Sufficient work was done to show that it would be possible, though perhaps, difficult, to make a counter sensitive to visible light. This was brought about by placing the counter in a vacuum system and arranging the point so that it could be pulled back into an atmosphere of potassium. After allowing the potassium to condense on the point it was replaced in the chamber and the whole filled with hydrogen Difficulty was experienced in getting a smooth coating of potassium. Probably a better method would be to first coat the point with a metal easily, oxidized, to which the potassium or other metal of low work function, would cling more tenaciously.

EFFECT OF NATURAL IONIZATION

It would seem from the experiments with free ions and with ultra-violet light that one ion is sufficient to set off the counter and that this ion does not have to possess any considerable energy. At least it seems more reasonable to assume that one ion rather than the accumulated effect of any particular number of ions sets it off. This ion no doubt has to enter the chamber at the proper place to be drawn into the sensitive region about the point, as shown by Hewlett.[3] However, it would seem that the natural ionization always present in the air would be sufficient to much more than account for the number of strays if this were the case. The natural ionization ascribed to penetrating radiations is caused by very high speed β-rays, or by recoil electrons. Hence a large volume might show an average ionization such as that found by electroscopes, but a small volume such as the effective part of that of counter might detect only a very occasional ionization at the instant the B-ray passed through.

EFFECT OF CONSTANTS OF THE ELECTRICAL CIRCUITS

Capacity across the counter seems to have no effect on magnitude of the discharges. If the counter was connected into a circuit capable of giving several hundred milliamperes without appreciable voltage drop the discharges were no more violent, ruling out the possiblity that stoppage of the discharge might be due to voltage drop.

The average current flowing to the chamber when counting briskly is of the order of 10^{-11} ampere. A galvanometer of 10^{5} megohms sensitivity when arranged to be used ballistically and connected in series with the counter shows a just detectable kick at a strong discharge. The series resistance can be increased until it is comparable with the leakage resistance of the counter before it has much effect, in which case it is necessary to raise the impressed voltage.

The counter was also used with an alternating current source. With this arrangement the capacity coupling between chamber and point produces noises which mask the counting action unless neutralized. This can be accomplished to a certain extent, by coupling the amplifier input capacitatively to another point of the transformer which is opposite in phase. The completeness of neutralization will depend to a certain extent on the freedom of the voltage wave from harmonics, the fundamental being very easily disposed of in this manner. The fact that counting action takes place under these conditions is a further indication that the process is of short duration.

SEARCH FOR COMPRESSION ABOUT POINT

The photographs (Fig. 1) were taken when the point was in action. The counter was set off by a spark whose light entered the chamber axially. At sometime later, the value of the interval being variable, the point was illuminated by another spark whose light entered through glass at one side, the microscopic camera being arranged at the opposite side of the chamber to take a silhouette photograph. Photographs were taken at several time intervals varying from practical simultaneity with the exciting spark to several thousandths of a second later. In no case, nor in visual observations, was any compression wave as suggested by Emeleus[19] detected about the point. This is not thought by the writer to prove the non-existence of such a wave, for it is quite possible that the phenomenon was not sufficiently prominent to be detected with the apparatus used.

INVESTIGATION OF TIME LAG

Measurements were made to determine if possible the time necessary

to set off the counter. A disk of 30 cm diameter with a slit of .523 mm width rotating up to 100 R.P.S. was used as a shutter. If δt is the time the point must be illuminated to set off the counter then the time the shutter is open can be expressed as $n\delta t$ where n is any number. Of this interval $(n\text{-}1)\delta t$ is effective for a starting a discharge. If the counter gives N discharges per second fully illuminated and R is the number of revolutions per second, the probable number of discharges per second

$$P_1=\frac{(n-1)\delta t RN}{1}=n\delta t RN-RN\delta t$$

$N\delta t=\theta/2\pi(1/R)$ where $\theta=$central angle subtended by the slit. For a 2 minute period the probable number of discharges is

$$P_2=\frac{120\theta N}{2\pi}-120RN\delta t$$

or

$$P_2=-(K_1)R+K_2$$

where $K_1=120\ N\delta t$ and $K_2=120\ \theta 2\pi\ N$

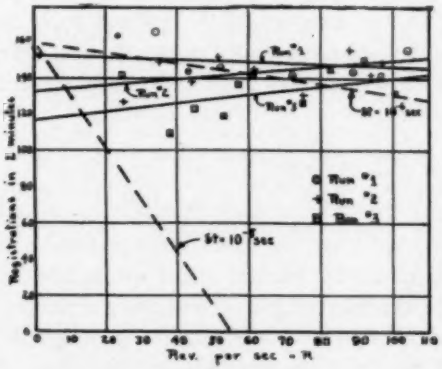

FIG. 11.

Fig. 11 gives the results of 3 runs, the number of discharges being registered automatically in these observations. These curves give the following data.

Run	K_1	K_2	$N=\frac{K_2}{60\theta}$	$t=-\frac{K_1}{120N}$
1	$-\frac{7}{100}$	147	2200	$+2.7\times10^{-7}$

2	$+\frac{18}{100}$	132	1980	-7.6×10^{-7}
3	$+\frac{23}{100}$	116	1740	-11×10^{-7}

This shows that the lag is certainly below 10^{-6} sec. as would be expected, but does not show how far below.

Emeleus[19] seems to the writer to have advaned the correct principles for the action of the counters, namely, explaining it as a purely ionization phenomenon, and not attributing it to a mysterious layer, either on the point surface,[11] or on the chamber surface.[12] It seems probable that space charges of low moblity will be built up, the positive, however, being more abundant than the negative, and the space charge sheath about the point being more important than that near the walls of the chamber.

There are four cases to consider. In order of importance as regards usefulness of the counter they are (1) the point negative in gases such as air and commerical hydrogen. (2) the point positive in gases such as air and commercial hydrogen. (3) the point negative in gases such as purified hydrogen, helium, and nitrogen. (4) the point positive in gases such as purified hydrogen, helium, and nitrogen.

In the first case when the counter is set off a positive space charge is built up about the point and a negative one near the chamber wall. Large numbers of the negative ions of low mobility will be deprived of their ionizing power by attachment to heavy molecules. The field strength increases near the walls and point and decreases between, and as the sheaths collapse into the electrodes the potential distribution returns to normal and the discharge dies out.

In case (2) there will be a negative sheath on the point and positive near the walls. But since the negatives ions of low mobility are less abundant, the stability will be less in this case than with the point negative and the working range will consequently be shorter.

Loeb finds that in pure He,[20] H_2,[21] and N_2[21] negatives ions of low mobility do not exist. Hence in case (3) there is no negative space charge near the walls, and the field in the space intermediate between the walls and positive sheath will not be reduced as much as in impure gases. Also the electons will be able to gain velocity sufficient for ionization by many free paths because of lack of attachment. Further, in these gases there is evidently a source of negative charges near the cathode whose origin is not fully understood but which is now being

investigated by W. Uyterhoeven at California Institute of Technology. There are insufficient data on case (4) to draw any conclusions. It seems, however, that behavior of points in different gases might profitably be investigated further.

PALMER LABORATORY,
PRINCETON, N. J.,
JUNE 1927.

REFERENCES

[1] National Research Fellow.
[2] R. D. Bennett—Thesis, U. of Chicago, 1925.
[3] C. W. Hewlet—To appear later.
[4] Zeleny, Phys. Rev., *19*, p. 567; 1922.
[5] Kovarik, Phys. Rev., (2) *9*, p. 567; 1917.
[6] Wulf, Phys. ZS., *26*, p. 382; 1925.
[7] Kolhörster, Phys. ZS., *26*, p. 732; 1925.
[8] Geiger and Rutherford, Phil. Mag., *24*, p. 618; 1912.
[9] Geiger, Phys. ZS., *14*, p. 1129; 1913.
[10] Greinacher, ZS. f. Phys., *23*, p. 361; 1924.
[11] Geiger, ZS. f. Phys., *27*, p. 7; 1924.
[12] Kutzner, ZS. f. Phys., *23*, p. 117; 1924.
[13] Zeleny, Phys. Rev., *16*, p. 102; 1920.
[14] Chattock, Phil. Mag., (6), *20*, p. 272; 1910.
[15] Kovarick and McKeehan, Physick ZS., *15*, p. 343; 1914.
[16] Geiger, Handbuch der Physik., *24*, p. 139.
[17] Kolhörster, ZS. f. Phys., *2*, p. 257; 1920.
[18] Emeleus, Proc. Camb. Phil. Soc., *23*, p. 85; 1926.
[19] Emeleus, Proc. Camb. Phil. Soc., *22*, p. 676; 1925.
[20] Loeb, Phys. Rev., *23*, p. 157; 1924.
[21] Loeb, Proc. Nat. Acad., *6*, p. 435; 1920.

FOCUSING ELECTRONS REFLECTED OR EMITTED AT EQUAL ANGLES FROM A PLANE SURFACE

By D. A. Wells

ABSTRACT

A method is proposed and the theory briefly given for focusing to a line all electrons of the same energy reflected or emitted at any given angle from a plane surface.

It was found that the lines of focus lie on the surface of a cylinder that is tangent to the center of the reflecting surface and having a radius equal to the radius of the path of the electrons.

INTRODUCTION AND DESCRIPTION OF METHOD

Recently the method of focusing electrons by a magnetic field has been used very extensively in the study of β rays and slow velocity secondary and reflected electrons. It has occurred to the writer that the same general method might be used to advantage in studying the direction of reflection of electrons as in the work of Davisson and Germer,[1] if all electrons that are reflected from a plane surface at any given angle could be focused to a single line. The possibility of focusing electrons reflected or emitted with the same energy and at any given angle from a plane surface is given below.

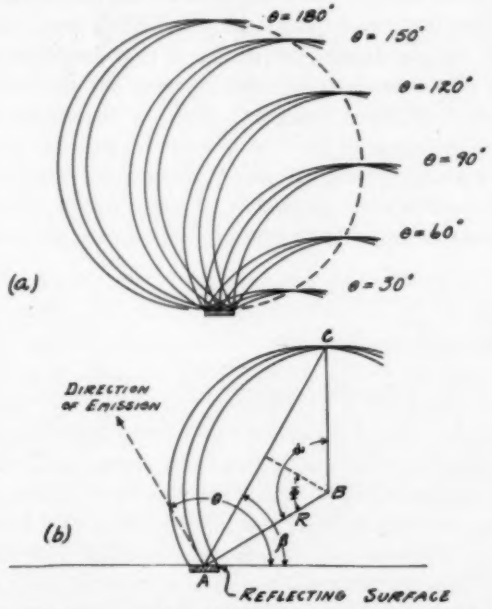

FIG. 1. *Showing manner in which electrons from a surface are focused.*

From (a) of the figure it is seen that all electrons coming from the surface at the same angle will be brought to a focus. Referring to (b) of the figure it will be seen that when the breadth of the reflecting surface is rather small in comparison to R, the radius of the path of the electrons (in the figure about one-fifth as great), BC is very approximately equal to R and also very nearly perpendicular to the face of the reflector. It is, therefore, obvious from the geometry of the figure that $\beta = \Phi$, and $\alpha = \Theta = 2\Phi$. From which $AC = 2R \sin \Theta/2 = 2R \sin \beta$, which is an equation for a circle in polar coordinates. Therefore, to a close approximation all electrons of the same energy leaving the surface in any given direction (in planes perpendicular to the magnetic field) will be focused to a straight line on the surface of a cylinder having a radius equal to the radius of the path of the electrons. When the magnetic field or the energy of the electrons is changed the line of focus moves along a straight line making an angle $\beta = \Theta/2$ with the face of the reflector.

CONCLUSIONS

It is suggested that the above method might be used in constructing an "electron spectrograph" having high resolving power and at the same time permitting the use of quite a large reflecting area. As a collector of the focused electron beams, one similar to that employed by Davisson and Germer would have to be used to keep out electrons of energy lower than that of those reflected. Due to the magnetic field the ordinary type of "electron gun" would not be suitable as a means of producing a primary beam. However the writer, using a coated filament and the ordinary slit method of focusing, has found that a homogeneous primary beam of good intensity can easily be obtained.

DEPARTMENT OF PHYSICS,
UNIVERSITY OF CINCINNATI,
CINCINNATI, OHIO.
JAN. 21, 1928.

[1] Davisson and Germer, Phys. Rev., *30*, p. 705; 1927.

A VISUAL METHOD OF SHOWING THE HIGH TEMPERATURE COEFFICIENT OF RESISTANCE OF METALS AS COMPARED WITH ALLOYS

By Paul Rood

One of the common properties of metals is their increase in resistance with increase in temperature and of alloys their small resistance change with temperature. A convenient way of demonstrating these effects for different metals and alloys, and the temperature range in which they are most marked, is to use a 201A vacuum tube with low voltage plate source and the grid potential controlled by the changing voltage at the terminals of a short section of wire as it is heated by a 6 volt storage battery. The same battery furnishes filament current. The circuit is shown in Fig. 1.

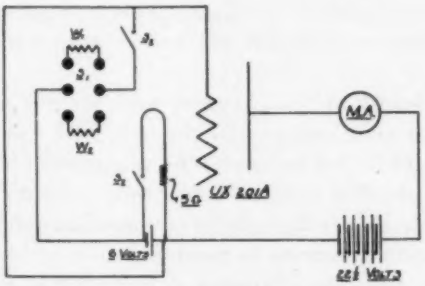

Fig. 1. *Circuit diagram.*

With a 30 cm section of iron wire, No. 14, in place at w_1, with 22½ volts on the plate, switch s_2 is closed. Two things are apparent; the wire heats to bright redness and the milliammeter increases its reading from near zero to about 3 milliamperes (a 0–5 milliampere meter is used). About 30 seconds are required for this change to take place. The increase in plate current is due primarily to one cause—the increase in resistance of the sample under test. The effect of change in resistance of the leads due to heating is negligible (leads include 6 feet of No. 12 lamp cord and heavy battery clips). To give the indicated change in plate current, the effect of the change in resistance is amplified in 2 ways. (1) Since the wire is connected between the grid (positive) and the negative end of the filament, we have ordinary grid amplification

of the increase in voltage across the wire. During a test the line current decreased from about 70 to 30 amperes, but at the same time the resistance increased enough to give a change of voltage of from 3.3 to 4.7 volts. This indicates a more than 3-fold change in wire resistance. Although a 6.15 volt storage battery, with internal resistance of about 0.015 ohm was used, due to voltage drop in the line and in the battery, we had available initially only the 3.3 volts at the grid and finally, when the wire was heated, 4.7 volts. Line drop is essential in making the test in this manner, for without it the grid voltage would be nearly constant. (2) As the grid voltage goes up the filament voltage, which is somewhat less than the voltage on the grid, due to the 5 ohm resistance, goes up accordingly, thus increasing the plate current.

It may be noted that on approaching 800 to 900 degrees (bright red heat) the iron shows but slight further change in resistance. Switch s_2 may be opened and closed at such intervals that the iron is kept between dull red and bright red temperatures and the corresponding meter reading change is found to be slight. This is in accord with the low values of resistance coefficient of iron at temperatures above 600 degrees C.

For a 30 cm length of No. 22 copper wire, the milliammeter reading change is on the same order as for the iron, with this difference—the reading continues to increase until the temperature becomes so high that hot spots develop and the wire breaks. Owing to the smaller dimensions of the copper the heating is somewhat quicker than for the iron. This continual increase in resistance even at high temperatures agrees with the behavior of copper as indicated in the tables of resistance coefficient for it over the temperature ranges involved.

In the case of 30 cm of No. 20 aluminium wire, quite similar results occur.

When 20 cm of low resistance coefficient alloy wire, No. 16, is inserted at w_2, on closing s_2 a constant milliammeter reading is obtained, not varying noticeably for any temperature between starting and the maximum obtainable.

The features of this apparatus are;

1. It differentiates between the resistance behavior of different metals and of alloys on heating. 2. The heating to redness electrically and the consequent increase in plate current take enough time so both the color effect and the reading may easily be followed with the eye. 3. The change in plate current measuring the increase in resistance is

relatively large. 4. The apparatus can be assembled and used with the expenditure of a minimum amount of time, the only parts being the board on which the meter, tube, and switches are mounted, a 22½ volt B battery, and a 6 volt storage battery.

DEPARTMENT OF PHYSICS,
WESTERN STATE TEACHERS COLLEGE,
KALAMAZOO, MICHIGAN.
MARCH 12, 1928.

A MOULD FOR CASTING CYLINDERS OF FINE POWDERS

By Jared Kirtland Morse

In powder analysis by the method of Debye and Scherrer, it has been usual to employ small tubes of special glass, celluloid or collodion to keep the powder in place while the exposure is in progress. These containers when of glass increase the exposure time and when of material containing carbon scatter the x-rays and cause considerable general blackening on the photographic plate. To obviate these difficulties, a method of casting these powders in place into cylinders approximately 0.075 cm in diameter and 1.5 cm long in the center of the

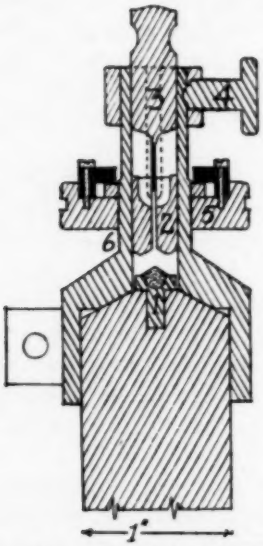

Fig. 1. *Mould. The portions of the mould made of brass are indicated by cross hatching and those of steel are shown in black.*

Debye camera, has been worked out in the Crystallographic Laboratory. The accompanying figure shows a cross section of the mould used. A little shellac is used to make the powder base, marked (1) in the figure, "tacky" so that the foot of the cylinder will adhere to it. The mould (2) is then screwed down tight and filled from the top with

fine powder. Care is taken to prevent too much pressure which would cause the crystalline particles to orient themselves. When the mould is full, the plunger (3) is set firmly with a set screw (4). This mould is then raised by means of the nut (5) on the thread (6). The plunger is then carefully removed and the whole mould is taken off from the brass leaving the powder cylinder without any container standing vertically in the center of the camera.

RYERSON PHYSICAL LABORATORY,
UNIVERSITY OF CHICAGO,
CHICAGO ILLINOIS.

AN ULTRAVIOLET LIGHT FILTER*

By Felix Saunders

Potassium hydrogen phthalate in one-fifth molar aqueous solution has been found to be quite opaque to ultraviolet light of wave length less than 3000A. The extinction beyond 3000A is so complete that this solution would make an excellent filter. Transmission is uniform in the visible and ultraviolet as far as 3000A. A film of the solution only one millimeter thick cut off sharply at 3000.

The solution is made by dissolving 40.836 grams of potassium hydrogen phthalate in water and making up to one liter. The potassium hydrogen phthalate was prepared according to the directions given by W. Mansfield Clark in his monograph *The Determination of Hydrogen Ions*. Several recrystallizations are necessary to obtain a pure product. The material used had been recrystallized eight times. The filtering effect is a function of the phthalate ion. A layer of solution 1 cm thick containing as little as eight grams of phthalate ion per liter is entirely opaque.

Fig. 1. *Spectrogram of potassium hydrogen phthalate.*

Figure 1 was taken with a Gaertner quartz spectrograph. The source of light was a spectrum tube containing hydrogen at 9 mm pressure. A potential of about 10,000 volts from a one-half K.W. transformer was applied to the electrodes, which were of aluminum. Each exposure was for fifteen seconds. Wratten and Wainwright panchromatic plates unsensitized were used. A mercury spectrum is shown for reference lines.

The University of Chicago,
Department of Physiological Chemistry,
Chicago, Illinois, Feb. 14, 1928.

* This work has been conducted under a grant from the Douglas Smith Foundation for Medical Research at The University of Chicago.

A PROJECTION ELECTROSCOPE FOR STANDARDIZING RADIUM PREPARATIONS

By L. F. Curtiss*

When large numbers of strong radium preparations are to be measured it is necessary to use extraordinary precautions to protect the observers from the gamma-radiation. The greatest protection, of course, is afforded by the inverse square law. For this reason the ordinary gold-leaf electroscope with reading microscope is unsatisfactory, since the observer must be very near the electroscope and consequently near the radium preparation. Moreover, there is always considerable eye-strain from the use of a microscope, particularly if care is not used in

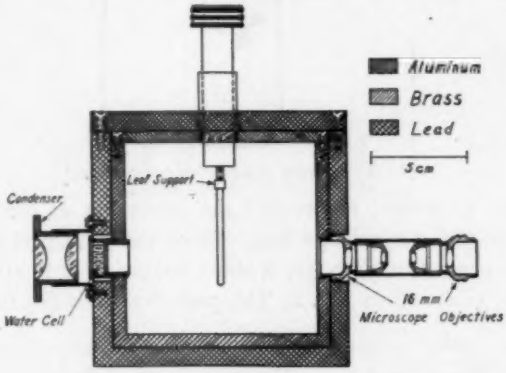

Fig. 1. *Cross-section of electroscope proper.*

focusing it. This may be serious if readings occupy several hours of each day, and the difficulty is further increased when several observers use the same instrument so that frequent refocusing is required. Some form of projection instrument will eliminate both of these undesirable features. This paper describes briefly an instrument which has been designed and built for use in the radium standardizing laboratory at the Bureau of Standards. This electroscope has been in operation for over a year and has proved very satisfactory.

In Fig. 1 is shown a cross section of the electroscope proper. To secure sufficient illumination to project the image of the gold leaf on a

* Publication authorized by the Director of the Bureau of Standards, Department of Commerce.

ground glass scale, so that it may be read in a laboratory room under ordinary lighting conditions, an automobile headlight bulb is used with a pair of condensing lenses. A water cell is placed in the wall of the

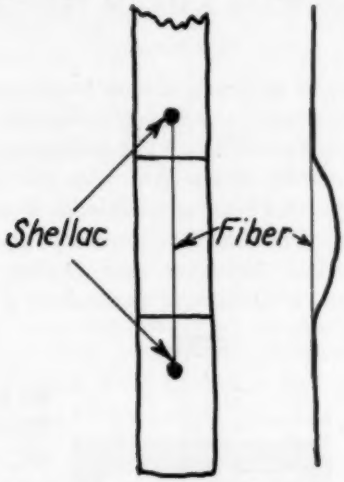

FIG. 2. *Method of mounting quartz fiber.*

electroscope, as shown, to prevent the formation of convection currents within the electroscope box. Since the gold leaf itself is not suitable for projection directly, a short quartz fiber is attached to it with shellac, as shown in Fig. 2. This provides a fine line for projection

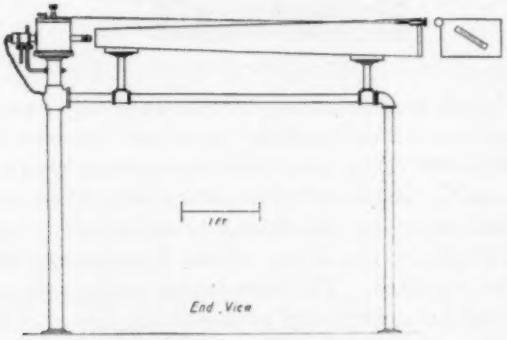

FIG. 3. *End elevation of complete electroscope.*

which can be magnified greatly without producing an image too large to use as an index on a ground glass scale. The projection lens consists of two standard 16 mm microscope objectives mounted in a tube as

shown in Fig. 1. The first objective forms an inverted, reduced image of the fiber at a proper distance from the second so that it in turn throws an erect and greatly magnified image of the fiber on the screen. The instrument as used at present magnifies the fiber nearly 100 times. This of course gives a much greater sensitivity than is obtainable with the usual reading microscope magnifying only 15 or 25 times. To shade the side of the ground glass screen opposite the observer from the daylight, a long tapered rectangular wooden tube is provided as shown in Fig. 3, which is a view of the end elevation of the electroscope and

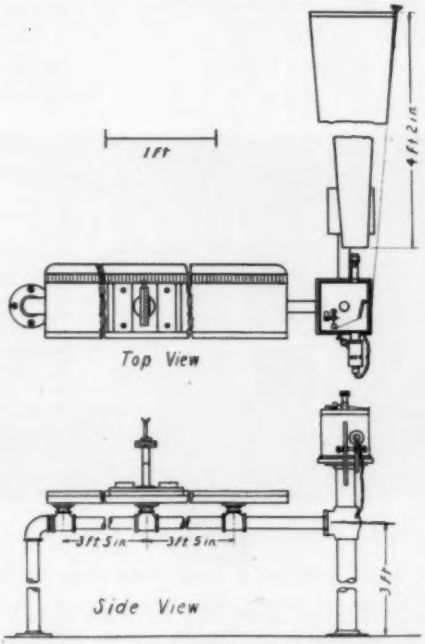

FIG. 4. *Top and side view of electroscope.*

supports. When the gold leaf is charged preparatory to reading the electroscope, the fiber is inclined about 30 degrees to the vertical and its image on the ground glass scale is inclined a like amount. Hence the scale is inclined as shown in the end view of the tube at the upper right of Fig. 3, so that the image of the fiber is parallel to the graduations. The electroscope is charged by means of the button mounted to the projection tube at the scale end and connected to the charging device on the electroscope by a wire.

A support for a shelf, which carries the holder for the radium preparations, is provided by a pipe extension running out at right angles to the projection tube as shown in Fig. 4. The radium preparations are placed in the small trough of aluminum which is supported opposite the center of one face of the electroscope. The base of the support for this trough may be moved along the seven-foot shelf. Its position, of course, must vary according to the strength of the preparation to be measured. The edge of the shelf is provided with a scale so that the support may be returned approximately to any given position and to aid in selecting the most favorable position for a given preparation. A glance at the top of the plan view in Fig. 4 shows that the observer is a conveniently safe distance from the radium preparation during measurement. The shortest distance, when the preparation is very near

FIG. 5. *Electroscope as mounted in the laboratory.*

the electroscope, and therefore a very weak one, is about 4 1/2 feet. When the preparation is strong, and near the end of the shelf, it is about 9 feet from the observer. Furthermore, when the image of the fiber is clearly focused on the screen for one observer, it is in focus for all others.

Fig. 5 is a photograph of the complete instrument mounted in the laboratory. The frame is made from standard pipe fittings and is sufficiently stable to protect the gold leaf from vibration under ordinary conditions. The high voltage lead for charging the leaf is brought along the floor under a wood strip and up the central support.

BUREAU OF STANDARDS,
WASHINGTON, D.C.
JANUARY 30, 1928.

A NEW VACUUM STOPCOCK

By A. P. H. Trivelli

Since M. W. Travers published, in 1901, his fundamental investigations on *The Experimental Study of Gases*, a number of suggestions have been made for a vacuum stopcock of glass, expecially to prevent the entering of atmospheric air into the vacuum system. Several of these suggestions have proved very useful in practice. In vacuum work, however, one always wants to have increased surety that his stops and connections are tight. Movable parts as in stopcocks require great attention in vacuum work. Stopcocks with solid glass stoppers have been used satisfactorily. In such a stopcock grooves may be ground at both ends, and can be filled with mercury, making splendid mercury seals. Such stopcocks must be used horizontally.

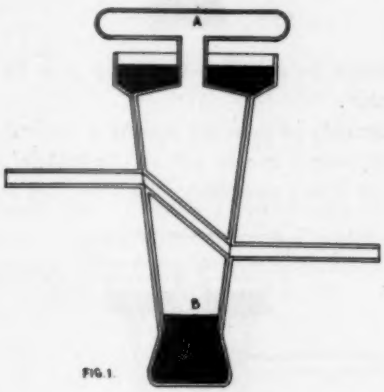

FIG. 1.

With high vacuum work, at less than 1 mm atmospheric pressure, it is desirable to make all connections, tubes, stopcocks, etc., as wide and as short as possible to save time in the evacuation. Stopcocks with solid glass stoppers have, in general, narrow tubes and cannot be recommended for wide tubes, because with increased dimensions the stoppers become so heavy that the whole stopcock is inconvenient in use.

A good mercury seal for a vertical stopcock is possible at both ends of the stopper if the latter is made hollow and is open at the top and bottom at *A* and at *B* (Fig. 1). The mercury can be put in with a

small funnel at *A* and can be withdrawn from the lower end of the stopcock with a narrow rubber tube connected with a pipette. The ground parts that have been smeared with grease or with phosphorus

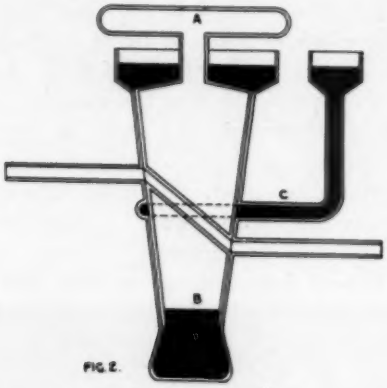

FIG. 2.

pentoxide can always be seen, so that any leak in that part is immediately detectable.

If still greater security in mercury sealing is desired, as for gas analytic work, a mercury ring *C* can be put in the middle of the stopcock as shown in Fig. 2. It is not necessary that this ring be put in the stop-

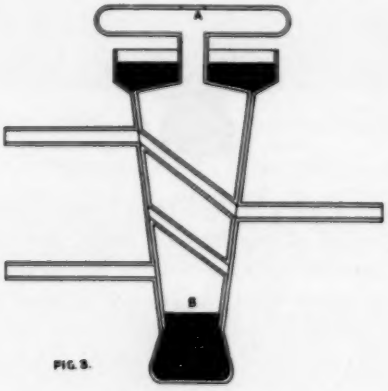

FIG. 3.

cock in the manner shown in the figure. The same result is obtainable by putting the ring in the stopper if it is more convenient for the glass blower to make such a stopcock.

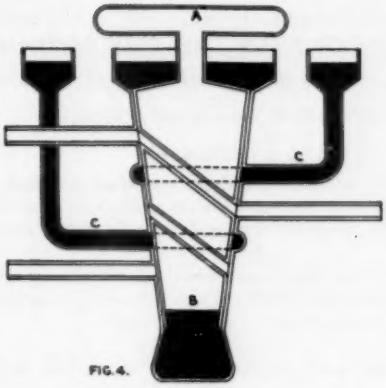

FIG. 4.

The same constructions are applicable in a three-way stopcock, as is shown in Figs. 3 and 4 which do not need further explanation.

EASTMAN KODAK COMPANY,
ROCHESTER, NEW YORK.

Flush Type Cases for Brown Continuous Chart Recorders. Where appearance is a feature, added attractiveness to instrument installations can be obtained by having the instruments supplied with special cases for flush mountings on switchboard or panels, the switchboard or panel being pierced to receive instrument cases. The Brown Instrument Company has long supplied its pressure gauges, thermometers and more lately its flow meters in flush type circular cases. Now the company is also able to furnish the Brown Continuous Strip Chart Instruments in cases of the flush type. A simple but important feature of the new Brown Flush Type Continuous Chart Recorder is an arrangement by which the recording mechanism can be drawn out of the case at the front for easy inspection, after which it can be pushed back into place, a locking device holding it firmly in position. Brown Continuous Strip Chart Recording Pyrometers, CO_2 Meters, Tachometers and Resistance Thermometers can now be furnished in flush type cases with or without panels as specified. All of these instruments can be supplied in single, duplex, multiple or multiple duplex models capable of producing from 1 to 12 records on one chart.

SOME FURTHER USES FOR THE NEON GRID-GLOW TUBE

By T. R. Wilkins and F. B. Friend

SUMMARY

Two applications of the three-electrode neon tube are described. The first shows how the neon tube can be used for the registration of alpha rays. One electrode of an ionization chamber is connected to the grid of the neon tube and the tube flashes on the entrance of each alpha ray.

In the second device, the tube is arranged to flash periodically and it is found that under certain critical conditions, a bias potential of a volt or two has a marked and easily measurable effect on the periodicity of discharge.

In 1921, Pearson and Anson[1] called attention to the fact that the Osglim lamp (a two electrode neon lamp, manufactured by the British General Electric Co.), if arranged as in Fig. 1, would oscillate at regular intervals.

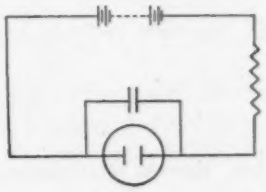

Fig. 1.

Taylor and Clarkson[2] soon afterward developed a simple formula showing that the period of flashing was directly proportional to the product of the resistance R and the capacity C. The two electrode neon tube has thus served as an extremely useful device for the comparison of capacities or of high resistances.

The problem soon suggested itself to various workers of trying the effect of a grid in the neon tube to see if its wonderful sensitiveness might not make it possible to use the third electrode for various delicate measurements. Shortly after work along these lines was started in this laboratory, the Westinghouse Electric Co. announced the Knowles' Grid-Glow tube and it has proved so extremely convenient that the devices here described have been developed with its aid.

[1] Pearson and Anson, Proc. Phys. Soc. Lond., *34*, p. 204; 1922.
[2] Taylor and Clarkson, Proc. Phys. Soc. Lond., *36*, p. 269; 1923.

Fig. 2 shows the details of this tube. If the grid is directly connected to the anode, a potential difference of about 350 volts causes the tube to glow. If the grid is left free, however, a negative charge accumulates on the grid and the discharge through the tube is blocked. The break

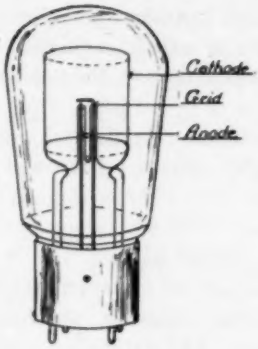

FIG. 2

down potential in this case is about 900 volts. Any device, such as a high resistance leak or a variation of the grid capacity, which will permit this negative charge to escape, removes the blocking action and allows the tube to glow. This action is capable of many applications in physical

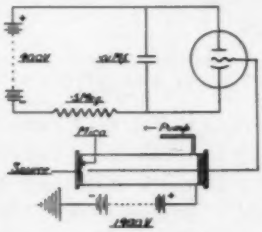

FIG. 3.

measurements. Two, which have proved useful are suggested here. Others are in course of development.

THE ALPHA RAY FLASHER

The first application to be described is for the recording of alpha rays. The experimental details are shown in Fig. 3.

A potential of about 400 volts is applied to the tube through a resistance of about .5 megohms. The tube was shunted by a capacity of .01 mfds. The grid was connected to the central electrode of an ionization chamber in which a thin film of uranium oxide served as the source of alpha rays. The effect proved to be most marked when the pressure in the ionization chamber was about two or three cms of mercury. The entrance of an alpha particle causes a considerable ionization. The negative ions go to the positive case of the chamber and the positives surge over to the grid. Thus the negative charge on the grid is neutralized and the tube flashes, indicating in a simple way the entrance of each alpha particle. The small condenser C keeps the time of luminosity small. The light of the neon tube is well suited for photographic registration. The discharge, moreover, is quite brilliant and is easily visible to a large audience.

An ionization chamber of the type utilized in the Geiger Counter has also been used. This has the advantage that the air in the chamber is at atmospheric pressure. The potential on the neon tube was about the same as before. The potential on the case of the ionization chamber was about 2000 volts. When a thin film of radioactive material is held in front of the opening into the ionization chamber, the entry of an alpha particle causes the tube to flash. A piece of paper placed in front of the radioactive film stops the alpha rays and no flashes occur. If a source of gamma radiation is brought near, the gamma rays penetrate the walls of the brass chamber and the tube flashes. Sheets of lead can be used to stop these rays.

THE NEON TUBE AS A SENSITIVE VOLTMETER

The circuit was arranged as in Fig. 4. V_1 was but several volts more than the voltage necessary to break down the tube when the grid was directly grounded. C is a capacity of .5 mfds and R_1 a resistance of about 1 megohm. A variable resistance here is of great help in securing the sensitive potential needed across the tube. The grid was grounded through a second variable resistance R_2 of about 10 megohms. It was then found that if a small positive bias potential was impressed on the grid through this large grid resistance that a marked effect was caused in the periodicity of the flashing of the lamp. The curves in Fig. 4 indicate that when the critical value of the grid resistance is secured, a fraction of a volt will cause a very marked difference in the period of flashing. This periodicity varies with the capacity C and can be made

as rapid as desired by decreasing the capacity—in fact a linear relation holds between the capacity and the time required for a given number of flashes. Thus photographic registration can be secured of changes in potential which are too rapid to be followed by a system of large inertia.

The curves are shown only for a positive bias but if the impressed potential should become slightly negative, the flashes slow down still further and so rapid changes in sign as well as in magnitude can thus be followed.

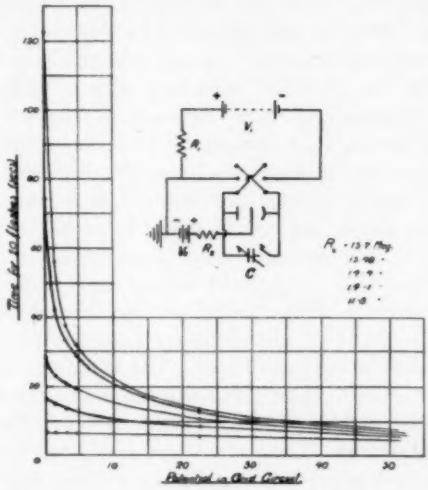

FIG. 4.

We have here a device in which a potential of a volt applied through a resistance of 15 megohms causes an easily measurable effect and by the variation of a condenser the flashes can be made of such a duration as to be separately counted or can be speeded up so that rapidly varying conditions can be photographically registered.

These two illustrations will serve to indicate that the neon grid-glow tube has great possibilities as a sensitive indicator. Applications to various other phenomena, especially in the field of ionization measure ments, are in progress.

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Einführung in die Theoretische Optik (Introduction to Theoretical Optics). By Dr. Max Planck, pp. vi+184, S. Hirzel, Leipzig, 1927; paper 6 Marks; linen 7.50 marks.

This charming volume is part 4 of the series by Prof. Planck, entitled "Einführung in die Theoretische Physik." It is divided into three parts.—the optics of isotropic homogeneous media, the optics of crystals, and dispersion in isotropic media. It assumes an acquaintance with electromagnetic theory and from the very start the subject is approached with the aid of Maxwell's equations. The assumptions involved are clearly pointed out and the derivations are extremely lucid. It begins with the treatment of reflection, refraction, spectral decomposition, interference, and polarization. Most of the treatment in this portion deals with the theory of plane unbounded waves. Geometrical optics is next taken up in a chapter so brief that its utility may be doubted. Diffraction problems are next treated, beginning with the classical derivation of Huygen's principle and proceeding from generalities to a discussion of special cases. Attention may be called to the ease with which the formula for the intensity distribution due to a diffraction grating is obtained by the use of imaginaries. The section on crystal optics is useful as a resumé of important equations. The reviewer feels, however, that a completely theoretical treatment of this complicated subject is of little use to a person approaching the subject for the first time. In this field detailed descriptions of experiments and of apparatus are necessary in order to give an adequate conception of the phenomena. The section on dispersion begins with the usual treatment of plane waves incident on a transparent medium composed of similar dipoles. It is followed by a brief treatment of an absorbing system of dipoles. Those who have read Prof. Ewald's resumé of dispersion theory in Fortschritte der Chemie Physik, and Phys. Chemie, *18*, Heft 8, 1925, will find it interesting to compare it with the treatment in Prof. Planck's book. The forerunner waves of Sommerfeld are briefly discussed and an excellent treatment of group velocity is given. The last chapter is a clear and satisfying treatment of the way in which wave mechanics arose from consideration of the analogy of ordinary mechanics and geometrical optics in an inhomogeneous medium. It is seldom indeed that a new theory receives such rapid acceptance that it is included in a formal and systematic treatise in the following year, by a leader of physical thought. Every active worker in the fields of optics and atomic structure will profit by a close acquaintance with Prof. Planck's book.

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